


210 Ft Advanced Antenna System
Report on Hydrostatic Bearing Damage

8 November 1965

(Advance Copy)


H. P. Phillips
8 November 1965

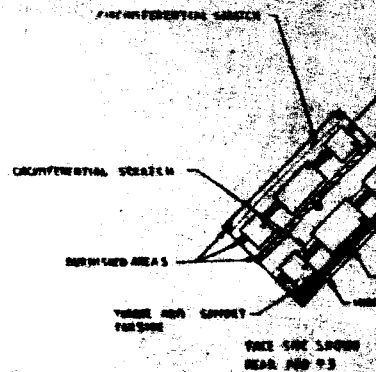

W. D. Merrick
AAS Project Manager

1. Summary

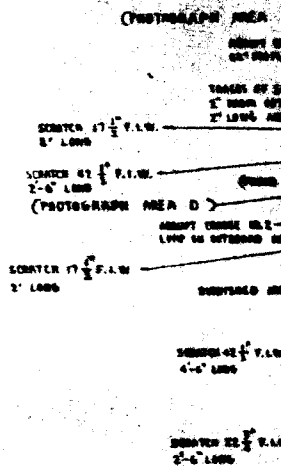
On 2 September 1965 an accident causing damage to the azimuth hydrostatic thrust bearing occurred during a routine azimuth rotation of the antenna by the contractor to test the cable wrap-up. Immediate inspection showed that the right front pad of the bearing had grounded and that the resulting force had broken the antirotation link support on the pad, permitting the pad to rotate and push out the reservoir walls (see photograph, Figure 4). Further investigation revealed severe gall marks about 3 inches from the inside wall and covering about 180 deg of the runner (Figures 6 through 12), on the right inside corner of the rear pad and along the full length of the inner sill of the right front pad (Figures 13 through 16). There were also minor scratches and burnish marks on the bottom of each pad and at various places on the runner surface. These are shown on the runner damage layout, Figure 1, and in the attached photographs.

A careful investigation together with tests on the hydraulic system has shown that the primary cause of the accident was mis-set relief valves in the hydraulic supply system. The resulting relief valve action cut down the flow to the pads below that necessary to maintain proper bearing operation. Other contributing factors were the partial closing of the shutoff valves downstream of the relief valves, undersizing of the high pressure filters and possibly the presence of foreign particles in the sill area under the pads.

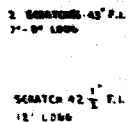
The accident was due entirely to human error and does not reflect on the basic system design. Safety interlocks are being included to prevent occurrence of a similar accident in the future. The damage to the bearing components resulting from the accident has now been repaired at contractor expense and the bearing is again operational.



RUNNER SEGMENT II



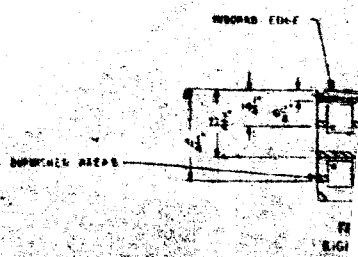
RUNNER SEGMENT I

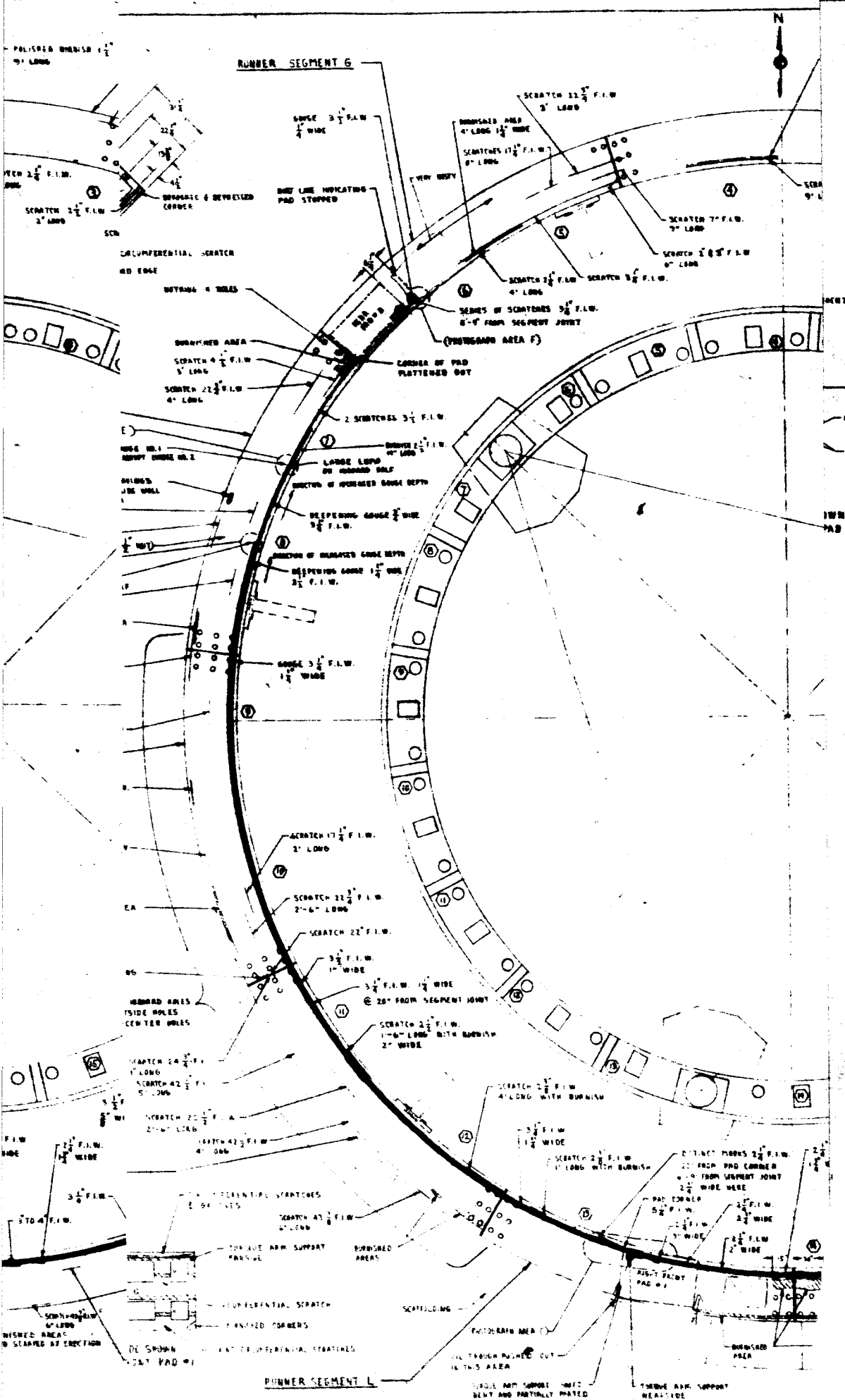


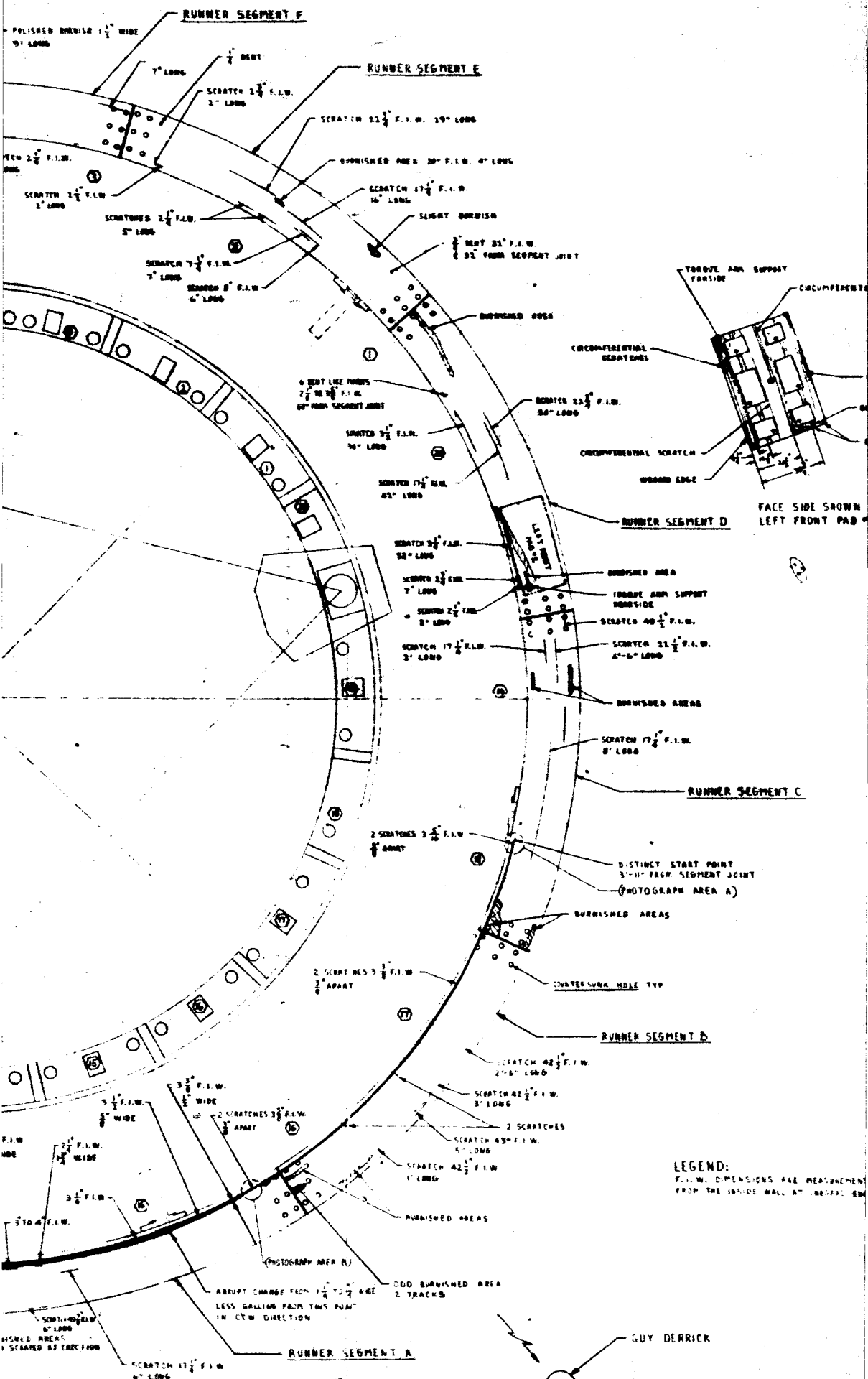
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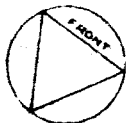
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RUNNER SEGMENT









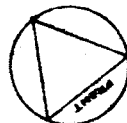
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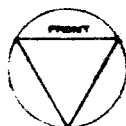
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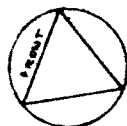
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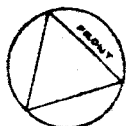
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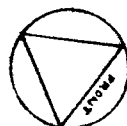
POSITION #5



POSITION #6



POSITION #7



POSITION #8

POS	DATE	TIME	AR
1	8-18-68	0830	37.0°
2	8-18-68	0900	15.5°
3	8-24-68	1100	57.5°
4	8-24-68	1200	140.0°
5	8-24-68	1330	0.0°
6	8-25-68	1430	230.0°
7	8-24-68	1500	45.0°
8	8-2-68	1630	314.0°

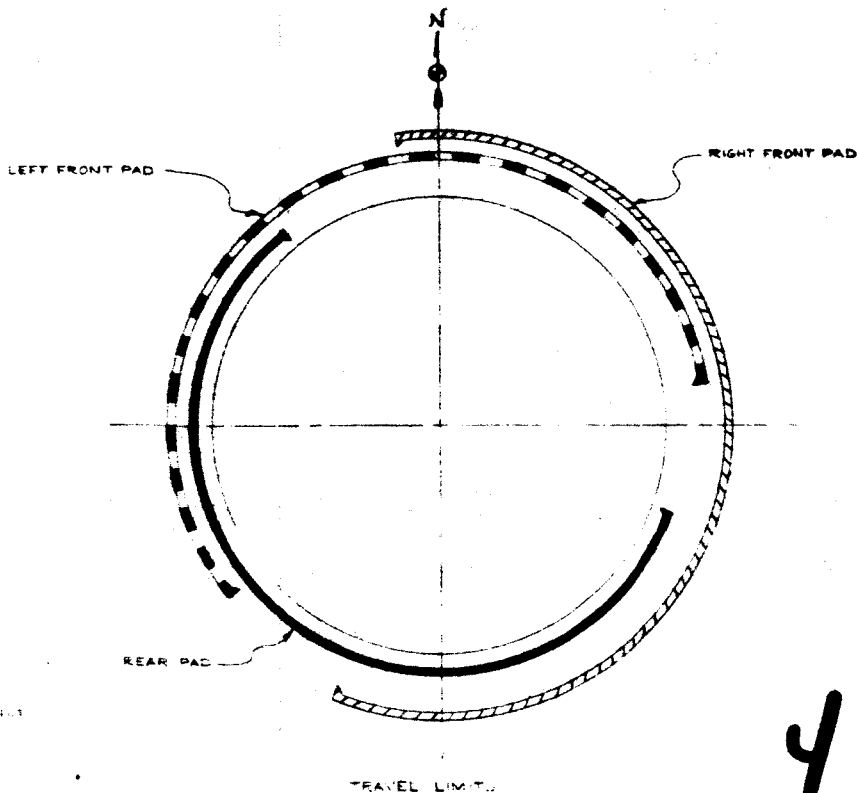


Figure 1

HYDROSTATIC BEARING
RUNNER DAMAGE LAYOUT

5K-134585

The action of the bearing under the conditions which existed because of the mis-set relief valves is within the patterns established by the original theoretical and experimental work done at the Franklin Institute during the design phase of the project (Franklin Institute Reports F-B2099 and F-B2015).

2. Failure Sequence

A thorough review of the antenna activities and data developed in subsequent tests reveals the following probable sequence of events leading up to the grounding and damage which occurred at 16:00 on 2 September 1965.

The bearing was originally put into operation 4 December 1964. Since then it has been used from time to time for antenna rotations required for construction and for bearing test purposes. No difficulties were encountered during these periods and all tests indicated that it was operating within the design parameters.

- On 9 June a thorough cleaning of the hydrostatic bearing was completed, the runner was inspected and the bearing was refilled with oil. At this time there was no indication on the runner of any previous grounding of the bearing pads.
- On 30 July all of the relief valves on the high pressure skids were set at 1500 psi by the bearing subcontractor and the bearing was considered operational.
- On 31 July JPL conducted film height tests on the right front pad and found operational film heights corresponding to those predicted on the original design. (See Appendix III.) Due to a misunderstanding with the subcontractor, at the completion of these tests the relief valves on the high pressure skid for this pad were left at 900 psi. Although the film heights were as expected, this relief valve setting is marginal for antenna operation. This is discussed in section 3 of this report.
- On 12 August the antenna was moved from position one to position two (Figure 1). No pad or runner marks are directly traceable to this motion.
- On 23 August a contractor technician fitted each high pressure filter with a differential pressure gauge and left the high pressure skids with the

relief valves set at approximately 900 psi for the corner recess circuits and approximately 1200 psi for the center recess circuits. This setting was too low to maintain full operational flow to all recesses of the bearing pads under normal operating conditions. The rear pad was in particular difficulty at this point because one of the skid pressure gauges, by which the relief valve settings were made, was reading approximately 150 psi high. Thus, in reality the relief valve for that recess was actually set below 900 psi. The effect of the low relief valve settings is discussed in detail in Section 3 of this report.

- On 24 August the antenna was move in azimuth clockwise from position two (Figure 1) through position three to position four in connection with the hyperbola installation and other construction operations. The evidence indicates that during this motion the right inner corner of the rear pad was dragging, cutting scratches about 1/16 in. wide and about .015 in. deep in the runner approximately 3 1/2 in. from the inner wall (Figure 11). The dragging force of the pad was accentuated by the action of the pad anti-rotation link, which tends, for this configuration of drag and direction of motion, to force the dragging corner into the runner while keeping the pad from rotating. (See Figure 2.)
- On 24 and 25 August in connection with placing the feed cone, the antenna was rotated counter clockwise from position four through position five to position six (Figure 1). During this motion the anti-rotation link, because the motion was in the opposite direction of that going from position two to position four, probably cleared the dragging corner of the rear pad causing little or no damage to the runner.
- On 26 August a JPL technician conducted further tests on the right front pad, finding that at that time the bearing was operating with the usual

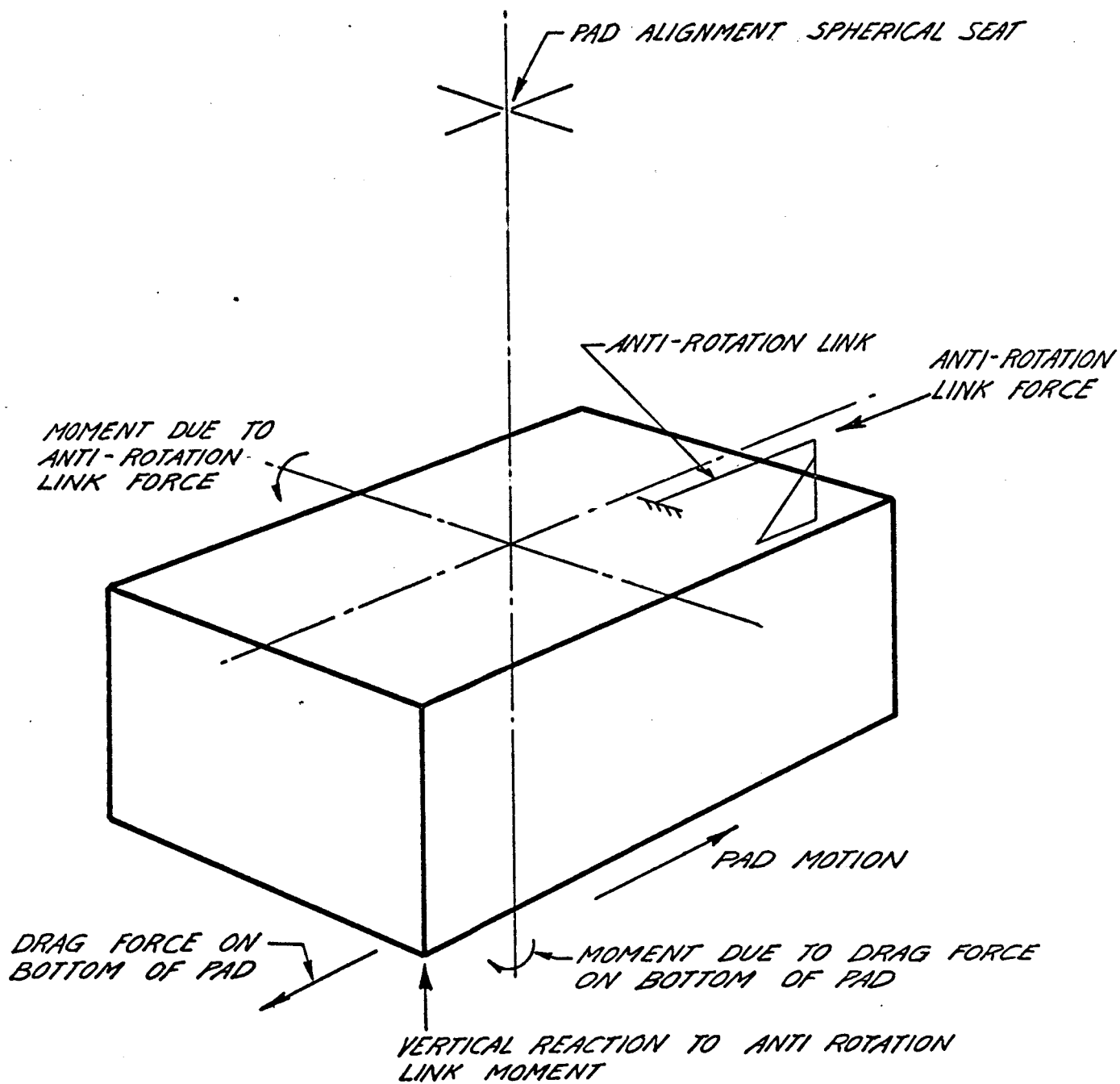


FIGURE 2
ANTI - ROTATION LINK ACTION

firm heights. At the conclusion of these tests the relief valves were set at 900 psi for the corner recess circuits and 1200 psi for the center recess circuits, comparable to the other pad circuits.

- On 30 August the antenna was moved clockwise from position six to position seven, and then on 2 September to position eight where the final damage occurred. (See Appendix I for detailed description of events at this time). During this motion the rear pad inner right corner apparently was again dragging, causing small scratches as previously described until it reached the 5 o'clock position on Figure 1, when the scratching changed to galling (Figures 6, 7, and 8). The galling continued until the pad was in about the 10 o'clock position (Figures 9 and 10). At this point first one lump then a second lump of metal were ejected from behind the pad, apparently relieving the galling so that no further serious damage was done by the rear pad during the balance of the motion to position eight. In the meantime the right pad encountered the crests of the gall marks left by the rear pad in the 5 to 6 o'clock section of the runner. These "cutting and abrading tools" caused severe damage over the entire length of the pad and finally resulted in so much rotational movement that the torque link, which normally restrains such rotation, was broken.

In considering the above chronology, it must be recognized that each pad was operating marginally because of the mis-set relief valves and because of high downstream pressure losses in the shut off valves and high pressure filters. These are discussed in detail in Section 3 of this report. The initial damage was caused by the rear pad even though the final stoppage was related to the right front pad. The left front pad saw only small scratches in the runner and was practically undamaged.

3. Hydrostatic Bearing Operation

A hydrostatic bearing, in its simplest form, consists of a pad and a runner. Fluid is forced through an opening to a recess in the bottom of the pad and escapes in a film to form the gap between the pad and the runner. The pressure in the fluid forcing it out through the film acts upon the area of the pad to support the load on the pad. In the 210 ft. AAS hydrostatic bearing six recesses in the pad extend the area under maximum pressure and serve to stabilize the bearing at uniform film thickness.

The AAS hydrostatic bearing requires constant flow to each of the recesses for proper operation. Oil from individual constant displacement pumps meets this requirement. As described above, the pressures in the recesses and in the oil flowing out under the pad act upward on the pad, supporting it and its load. If the load is increased the pad will sink slightly reducing the film height between the pad and the runner and hence the cross sectional area available for flow. The reduced flow area requires a higher pressure to discharge the constant oil flow, restoring equilibrium between the oil pressures and the load.

In normal operation the bearing is extremely stiff. For constant oil flow and oil viscosity the film height varies inversely as the third root of the load, so that doubling the load will decrease the original .010 in. film height only approximately 0.0016 in. for the AAS bearing in normal operation.

If the oil supply is modified so as to have a constant pressure such as that provided by a pressure regulator, rather than a constant flow, the bearing has virtually no stiffness (neglecting the flow losses in the line). Any increase in load will cause the pad to settle until the pattern of oil and direct contact pressures under the pad is in equilibrium with the load. In this case flow is governed by the available flow passages along the pad face from the recesses out to the reservoir, and by the pressure of the supply system. The

equilibrium mechanism of the constant flow source system described above does not exist and the pad will drift downward until a pressure-load equilibrium is reached. This point is discussed in Appendix II in a report made by Dr. V. Castelli after an inspection of the bearing damage. Dr. Castelli did the basic design of the bearing for the Franklin Institute.

With a constant pressure flow source the effect of pressure losses in the lines between the pump and pad is to decrease the pressure available in the recesses at high flow rates and to increase the recess pressure to approach the source pressure at lower flow rates. This characteristic given the bearing a marginal stiffness because increased load will lower the film height and the flow. The lower flow has less pressure drop in the lines, and more pressure is available in the recesses to carry the increased load.

The pressure relief valves used to protect the system against over pressure will function like a pressure regulator if the downstream pressure exceeds the relief valve setting. With the multi-recess pads used on the AAS where independent flow sources are provided for each recess the situation is quite complex. With the relief valves set too low, as they were at the time of the accident, it is possible for the pressure in one recess to reach the relief valve setting in that recess supply system while the other recesses are functioning normally. In such a case, depending on the flow between the recesses and the related pressure patterns, supply flow to that recess may be cut off entirely. This may cause other recess pressures to reach the trigger relief valve pressure in the respective circuits and the pad drops like the proverbial lead balloon.

From the data available pertinent to the rear pad, it appears that at least one, and possibly as many as 4 recesses, had operational pressures exceeding the relief valve setting. It is not possible to determine the status

of the front right pad, which was most severely damaged, although at the time of the last JPL tests it was functioning at normal film heights.

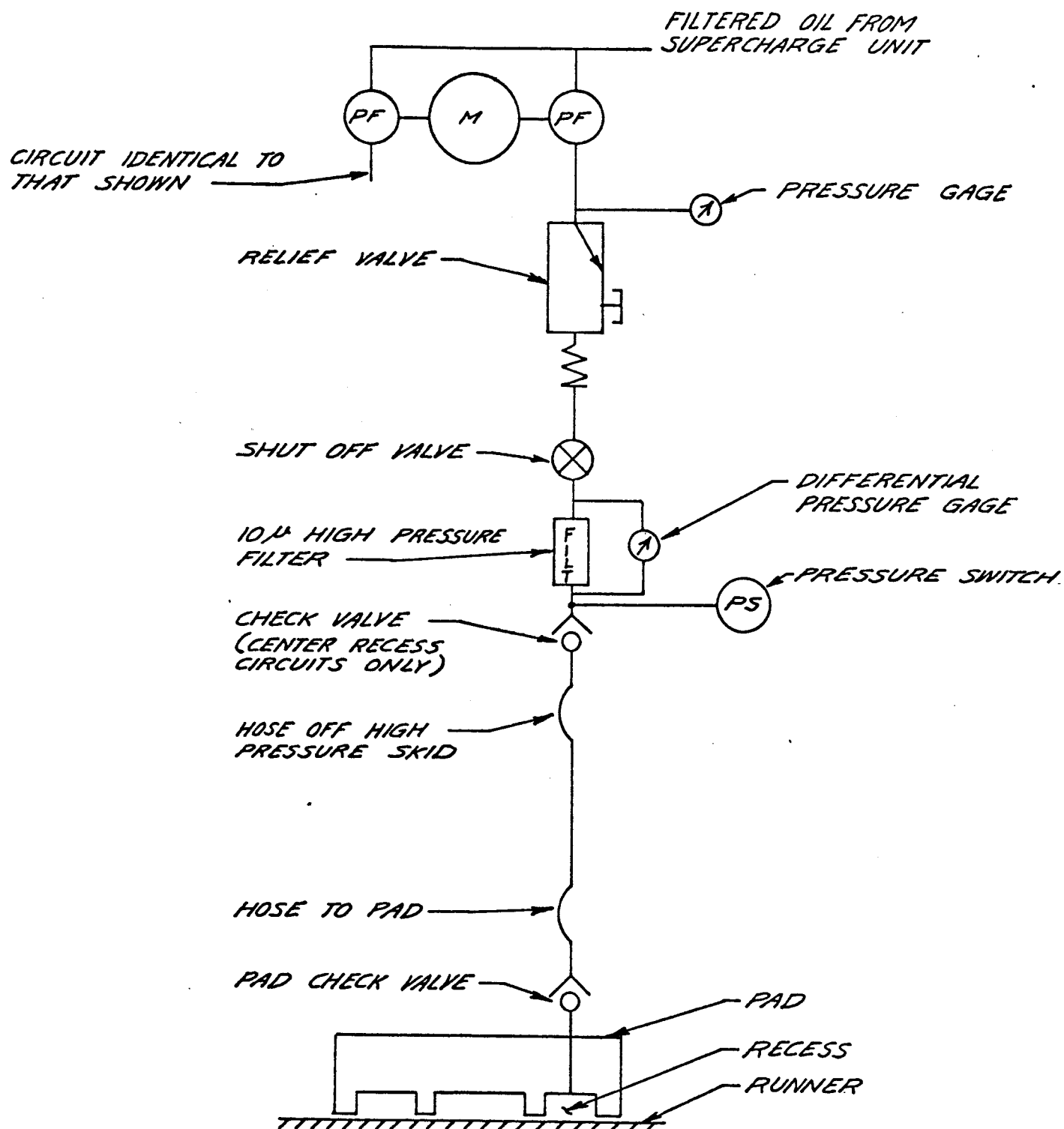


FIGURE 3
 HYDROSTATIC BEARING HIGH PRESSURE
 CIRCUIT

4. Analysis of the Causes of Accident

The high pressure supply system for each recess consists of an electric motor driving a constant displacement pump, a pressure relief valve, a shut-off valve, a high pressure filter, piping and hoses to the pad. A check valve at the pad entry serves to prevent flow from the pad back into the lines in the event of line breakage or pump shutdown; this is shown schematically in Figure 3. The definite or possible contributions of each of these elements to the failure is discussed below:

(a) Constant Displacement Pumps

Field measurements on the constant displacement pumps showed a flow rate of approximately 8.2 gpm instead of the 7.5 gpm specified in the design. This flow increase would cause a slight increase in film height and would be a benefit, rather than a contributor to the difficulties.

(b) Pressure Relief Valves

Investigation after the accident revealed that all of the relief valves on the rear and left front high pressure skids were set for too low a relief pressure so that in normal operation some or all of the flow to the individual recesses might be diverted to the return line, depending on the conditions existing in the pad pressure patterns at any given time. The relief valves on the front right skids were changed during the field operations immediately prior to the final stoppage, so that their position is not known for certain. However the last setting, made 26 August, was similar to that on the other skids.

The relief valve settings, checked against gauges calibrated with a dead weight tester on 23 September were as follows:

Recess and Location		Rear	Front Right	Front Left
1	Corner	950	3000	900
2	Center	1200	2050	1200
3	Corner	1080	3000	900
4	Corner	1000	900	1050
5	Center	1200	1200	1250
6	Corner	810	1600	900

All of the hydraulic components in the high pressure circuits are rated for 5000 psi service except the pressure gauges which were 3000 psi. With these components relief valves settings of 2500 to 3000 psi would have been in order.

(c) Shutoff Valves

After the accident it was found that several of the shutoff valves downstream of the relief valve were partially closed. Tests run on the valves in the field indicate that the pressure drop across these valves as set was in the order of 200 to 300 psi for the full flow of oil through them. In this condition they would tend to cause the pressure relief valves to function at a lower recess pressure than if they were fully open, and hence increase the chance of the triggering relief valve acting as a pressure regulator, or constant pressure source.

(d) High Pressure Filters

Tests conducted on the high pressure filters after the failure showed a pressure drop of 80 to 100 psi with the full flow of oil at 110°F. For cooler oil, as might be found in initial motion, the pressure drop would increase with the increasing viscosity.

(e) Piping, Hoses and Downstream Check Valves

The pressure drop through the piping, hoses and downstream check valves, as measured in the field was approximately 25 psi. This

pressure drop, along with that of the filters and the shutoff valves discussed above, acted to give the bearing a marginal stiffness under the constant pressure conditions provided by the relief valve after its setting was exceeded

(f) Oil

The hydrostatic bearing is designed to operate with an oil having a viscosity of 560 SSU. The bearing oil was tested after the accident and was found to have a viscosity of 661 SSU. The effect of the increase in viscosity of 661 SSU. The effect of the increase in viscosity is to increase the pressure losses in the lines and filters and to increase the bearing film height slightly under ordinary operating conditions. The action of the oil with increased viscosity was beneficial to the bearing at the time of the accident.

The recess pressures calculated during the design of the bearing were 750 psi for the corner recesses and 900 psi for the center recesses, based on full flow to all recesses and a 1.5×10^6 lb total pad load. The pad load measured by the pressure in the hydraulic jacks lifting the alidade corner at the time of removal of the pads for repair was 1.6×10^6 so that these figures should be increased approximately 6 percent to 800 and 960 psi respectively.

From the information presented above it appears that the relief valve settings for the corner recesses were marginal. Using these calculated recess pressures and the measured flow losses in the high pressure filters and the lines, results in a critical relief valve setting of approximately 900 psi. Hence any additional losses due to the partial closing of the shutoff valves, or recess pressure variations, would trigger the relief valve, making it function as a pressure regulator. On the same basis the normal pressure at the relief valves for the center recess circuits is 1050 psi. With a 1200 psi setting there

is more possibility that full flow would be maintained in these circuits, but the settings were marginal for operation.

It is concluded that the dragging of the corner of the rear pad is directly related to the very low relief valve setting for recess No. 6 and that the flow to the other corner recesses may have also been reduced, causing near zero film height over the rest of the pad. Certain patterns of scratches on the runner and on the left front pad face indicate that at least while the antenna was in position five, the front left pad operated also with marginal film height, although it never became involved in a serious scoring of the runner. The right front pad operation is an enigma, because tests conducted on 26 August indicate it was operating with normal film height at that time and the marks on the bottom of the pad indicate that at least part of the time it was operating on minimal film height. Because of the uncertainty of all of the operating conditions it is not possible to conclude definitely when the front two pads were operating improperly. There is no question that the rear pad was not operating properly after 23 August and that the front right pad grounded on the crests of the resulting gall marks.

5. Repair and Tests

Immediately after the accident on 2 September the oil was drained from the hydrostatic bearing reservoir. Inspection of the runner the next morning indicated that the bottom of at least the right front pad was damaged and possibly the other two also (at this time the sequence of failure had not been developed). Work was started immediately to remove the pads in accordance with the procedure which had been developed during the design phase of the bearing. Four jacks were used to lift the alidade corner weldment, steel stools were set in place and the corner weldment was lowered onto them. These stools were capable of supporting the antenna in a 120 mph wind. Rails were then fastened to the under side of the corner weldment and trolleys were fitted to carry the pad. Turnbuckles between the pad and the trolleys were used to lift the pad and it was then rolled out on the track to a point where it could be lifted clear with a crane. The photograph of Figure 3 shows the pad in position ready to be moved out.

Runner repair was accomplished by chipping and grinding out loose metal and filling the groove by arc welding. The welds were then hand ground roughly and finished by hand with a file until the original flatness requirement of .003 in. over 60 in. was met. Actually the maximum out of flatness in the repaired area is approximately .002 in., and the area can be detected only by the difference in texture between the original machine finish on the balance of the runner and the file finish in the repaired area. The process is shown in Figures 19 through 23.

Tests on the relief valves were conducted at the Rohr Corporation on 6 September and subsequent tests, duplicating operating conditions were conducted in the field on the pumps, filters, relief valves and other components.

The damaged pads were taken to a shop in Los Angeles where the damaged portion was repaired by welding, the faces remachined and a new phosphate

coating was applied. Total metal removal from the original was less than .005 in. and the original flatness tolerances were met.

The bearing was reassembled with the reservoir walls repaired and repainted and the entire assembly returned to new condition. All of this work was done by the general contractor, the Rohr Corporation, and the bearing subcontractor, the Rucker Company, at their own expense with no cost to The Jet Propulsion Laboratory or to the government.

6. Hydraulic System Modifications

After a thorough review of the hydraulic system and the overall bearing operation the following modifications are being made to the pad hydraulic systems and interlocks:

- (a) A flow switch set to actuate at approximately 4 gpm is being placed just upstream of the relief valve at the pad for each circuit. These flow switches, together with a logic circuit, will turn on a warning light in the control room if flow to any recess drops. Azimuth motion will be shut should a pattern of flow failures giving inadequate bearing support occurs. It should be noted that the bearing will operate safely when flow to any one recess is stopped and when flow to a number of combinations of two recesses is stopped.
- (b) The skid pressure gauges which have a 300 psi range are being replaced with gauges having a 5000 psi range which will permit setting the relief valves at 3000 to 3500 psi (well above the expected operating range but within the capacity of all of the system components).
- (c) Film height gauges are being installed at each corner of each pad. These will:
 - 1. Light a warning light in the control room if any corner approaches within .006 in. of the runner.
 - 2. Light a red light and shut down azimuth motion if any pad corner approaches within .003 in. of the runner.
 - 3. Provide continuous monitoring of the film height in the control room.

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- (d) A visible type flow meter has been installed in the drain lines at each skid to detect leakage flows from the pump case drains or through the relief valves. This is also of assistance in testing the pump conditions without removal from the circuit.
 - (e) Flagged locks are being placed on the relief valves and the shutoff valves. These locks must be removed to adjust the valves and their presence assures that the valve is in proper position for operation.
 - (f) The runner joint bolt holes were plugged because dirt which might have settled in them was a suspected cause of some of the pad damage observed. This was accomplished with a low melting point alloy which was poured in place with a key to secure it and then finished flush with the runner surface.

APPENDIX I

Statement by Don McClure (Jet Propulsion Laboratory Site Resident Engineer)
regarding the hydrostatic bearing failure on Thursday, 2 September 1965.

"I returned to the Mars Site from the Echo Site at about 4:15 p.m. The antenna had been rotated in azimuth approximately 180 degrees. Shortly after arriving, D. Ramsey (Rohr Construction Site Superintendent) told me that they had been rotating in azimuth when the antenna appeared to come up against a hard spot. He said he noticed that the recess pressures on the right front hydro bearing pad were not normal. The pressures indicated to him that the pad was caught or tilting, and had not righted itself. He said that he checked the pressure relief valves on the skid and checked the skid from one end to the other and all controls on the high pressure skid for the right front pad appeared to be normal. He then set a crew of men to work greasing the sockets that had been greased about two weeks earlier by a Representative of The Rucker Company. While the men were greasing the sockets, D. Ramsey and I discussed the apparent tilting of the pad, and why the pad had not righted itself. To determine if the pad had grounded, we decided to take up a set of feeler gauges and measure around the pad while it was floating to see if it was grounded. We went, and D. Ramsey checked the pad using feeler gauges and determined that, as facing the pad looking toward the center of the antenna, the left front corner was up to about 3 thousands of an inch, the left rear corner was up about 10 or 12 thousands of an inch. On the right

side he indicated that it was up about 10 thousands of an inch. Wondering if the pad had scored the runner, we decided to move the pad back away from this spot about three or four feet. He sent Walt Haas up to rotate the antenna in azimuth, while he (D. Ramsey) felt the runner surface after the pad moved away from it. After some exercising as to which direction was the proper way to go, the pad moved to the left or original direction of travel, probably a foot and then was returning back to the antenna's original position. D. Ramsey was feeling the runner when there was a sound, which sounded like rubber rubbing against metal. At that time we all jointly agreed that the pad had finally righted itself. Within a few seconds, the antenna was still moving, there were several loud cracking or popping noises. I then saw that the anti-rotation link stub in the pad had failed and bent, and the pad had caught, so that the left front corner hit the outside through wall. At this point, oil started to leak and after considerable amount of yelling, the antenna was stopped. The work then started in plugging this leak with rags."

VITTORIO CASTELLI, PH.D.

Report on Visit to 210'-AZ-EL Antenna at Goldstone on
Sept 17 and 18, 1965

At the invitation of the Jet Propulsion Laboratory, I visited the Goldstone site for the purpose of examining the damage and history of the azimuth bearing failure, trying to establish the causes of such failure, and making recommendations for the future.

My conclusions can be divided into three groups:

a) causes and modality of failure; b) repairs and modifications; c) tests and long range recommendations. The ideas in these groups are expounded in what follows.

a) Causes and Modality of Failure

From all evidence at the site, it can be concluded that the controls at the three bearing pumping stations were tampered with or mishandled in such a manner that the bearings were operating at approximately full load carrying capacity but close to zero stiffness. This was accomplished by resetting the pressure relief valves which are located in the line between the high pressure punps and the recesses at an unsafe value of the pressure (approximately 900psi. No accurate numbers on these settings can be obtained due to lack of calibrations of the field gauges and the laboratory gauges). To compound the seriousness of the situation the valves which are directly upstrem of the recesses (yellow handle valves) were found open by less than one full turn

VITTORIO CASTELLI, PH.D.

(the full implications of this action are hard to assess with certainty because of the lack of charts of valve characteristics)].

Although the pressure settings were close to those registered by the gauges during normal operation, the ~~pressure~~ system failed because it was forced to operate at constant pressure rather than at constant flow as it was designed. The only stiffness of the system was provided by the bell shape of the film and the small resistances in the line from the relief valves and the recesses (this includes the yellow valve losses). The designed stiffness is close to infinity for all practical loads. This means that the designed film would be maintained under great variations in load. However, after these acts of benevolent sabotage the stiffness was approximately zero and only came into the picture when the film was nearly collapsed.

To elucidate these points, it must be pointed out that an operational bearing system need not only be able to supply lubricant at the pressure needed to carry the load at steady state, but also should raise the feeding pressure when the load increases and the film thickness decreases. This feature is called stiffness and makes the bearing a stable system since it can oppose all perturbing forces.

The stiffness of a constant flow system is due to the fact that the feeding pressure can rise as much as needed to push a given amount of fluid through the bearing clearance in a given time. This happens regardless of load. But, if

VITTORIO CASTELLI, Ph.D.

the feeding pressure is limited by a pressure relief valve, the system stiffness becomes zero any time the feeding pressure needs to become higher than the valve setting (which is when stiffness is needed the most).

Due to the fact that the relief valves were set at nearly the correct operating pressure, the bearing was carrying most of the weight of the antenna but, due to the lack of stiffness, could not establish any film. Contact occurred over large areas of the bearing pads although the contact forces were rather small. (some film thickness was established due to film shape effects and line resistance effects which come into play at small flow rates but which I shall not discuss in detail here). Burnishing marks are evident to demonstrate the validity of the above statements. When some debris or some particular circumstances were met by the rear pad, scratches developed and degenerated into complete failure during the course of two passes. When the left front pad passed over the scored area it failed also. The right front pad never passed over failed regions of the runner and shows only burnishing marks of varying intensity.

To summarize, the system failed because of restrictions and mistaken settings imposed on the feeding system against the specifications and the directions of the instruction manual.

The system is quite simple in its outward appearance and many people may have drawn the conclusion that they really understand how it operates but in the course of

VITTORIO CASTELLI, PH.D.

time events have occurred which have shown the contrary about some people, in responsible positions. (This point could be elaborated upon with at least four examples of serious misconceptions which I found personally. No system will ever be idiot-proof and strict instructions will have to be furnished and enforced for the antenna to survive.

As far as the intensity and the pattern of the failure is concerned, it is obvious that the pad constraint mechanism (the mechanism that prevents the pad from rotating about a vertical axis) aggravated the situation by driving one of the pad edges down onto the runner. The fact that this was a design error was known to all concerned before the failure. To alleviate the feeling of regret for not having modified this feature it can be observed that, unless the constraint mechanism started the galling process, the failure would have progressed to the point of giving obvious hints such as smoke, sound, etc. Therefore, the constraint mechanism may only be responsible for accelerating the failure but not for causing it.

The monitoring system showed to be inadequate, since it failed to show any signs of the poor operating conditions which must have persisted for many days. Pressure readings should be taken downstream of all major resistances in the feed lines if they should indicate recess conditions. The positive detection of flow to the bearing is essential since it defines a "go" condition.

VITTORIO CASTELLI, PH.D.

The fact that the pressures in the various recesses are usually unequal should not misconstrued as poor operation since such is the optimum design condition. Above all, no attempts should be made to equalize the pressures by means of relief valve settings, etc.

As far as the timing of the failure and its causes is concerned, the only statement that can be made is that damage started on 8-24-1964. By then the valves had been misset. However, due to the nature of the failure it is hard to say how long before the start of the damage the system tampering had occurred. The assessing of responsibilities may be difficult since it is possible that the general notion had been created to set the system in the mistaken way. Therefore, it is possible that several people set the relief valves in the wrong way at different times and that the system ran in an extremely poor condition for nearly a month until a chip or other fortuitous event started the serious failure.

b) Repairs and Modifications.

All scratches on the runner and pads of width greater than $3/16$ " and depth greater than .020" should be filled and ground back to the original tolerances by a suitable process. Phosphate treatment should also be reapplied since it showed to be beneficial in all light contact areas. Minor scratches should be stoned so that they present no asperities.

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Taking advantage of the occasion that the bearing pads are back in a machine shop, the pad constraint mechanism should be changed to a type which limits its action to preventing rotation of the pad without introducing extraneous forces (this has been discussed with Mr. Horace Phillips of J.P.L., Mr. John Bates of Rucker, and Mr. Salvatore Rocci of Rohr).

The feeding system should be modified according to this:

- 1) flow to the recesses in excess of a preset minimum should be readily detected to indicate safe operation (this can be accomplished by means of Venturi tube in the feeding line);
- 2) the recess pressures ~~xxx~~ ^{should} be measured downstream of all filters, valves and other major resistances;
- 3) the relief valves are in the lines to protect the pumps and motors from the consequences of plugged high pressure filters. As such, the valves should be set at more than 4000 psi., held there by means of pins and possibly sealed;
- 4) the gate valves downstream of the relief valves are in the system to help set the relief valves and to enable check-out crews to carry out performance tests. When such chores have been accomplished, these valves should be secured at their full open position by means of pins and possibly sealed;
- 5) the maintenance and operation manual issued by the Rucker Company never mentions the relief valves in the set up procedure as it probably assumes that Rucker personnel should have set such valves when the system was delivered.

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Not as readily explainable, however, is the absence of any mention of the relief valves in the trouble-shooting procedure section. The manual description of the system functioning is not sufficiently terse. Even the fact that this is a constant flow system and how such a system operates cannot be readily gathered. Therefore, portions of the manual dealing with the system descriptions, initial set-up, check-out procedures, and trouble-shooting should be rewritten. Moreover, a brief but clear set of instructions should be attached to each of the bearing stations (possibly on ebossed plate).

6) the Rucker manual is also not clear on how many super-charge pumps should operate at any one time. This should be included so that no doubts can arise on the fact that both pumps should be operative with some simple detection system to detect if any one of the pumps goes out of order.

Active redundancy is preferable to stand-by from the point of view of reliability and the resulting extra filtering will definitely be useful to the oil.

7) clear responsibility of the operation of the bearing should be assigned to one person at the site. Such a person should be thoroughly instructed by Mr. Phillips, Mr. Bates, or me on the basic ideas behind the design. Then he could draw intelligent conclusions about any benevolent sabotage ~~attempt~~ attempted in the future. As an example of such threats I will mention that, on my last visit to the site, I heard

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the rumor that the retaining plates of the runner joint wedges were intended to be removed because they "are a nuisance in sealing the trough wall"! Due to the considerable motion of the runner(both axial and circumferential) this would result in almost certain disaster.

9) Since I was responsible for the basic design of the system and I am very interested in its success from the point of view of its significance to the state of the art, I propose that I advice on any possible change, testing, instructing, and manual writing involved with the hydrostatic bearing. I will be glad to perform these services free of charge.

c) Tests and Long Range Recommendations.

A set of tests should be performed to establish the characteristics of all parts of the system. I particularly recommend: to determine: 1) the high pressure pump flow rates at various pressures up to 4000psi; 2) the filter resistance; 3) the resistance of check valves; 4) the recess pressures and film shapes for sample antenna positions and all pump failure combinations contemplated in the design; 5) recorded history of recess pressures throughout one complete revolution of the antenna; 6) data on the behaviour of downstream pressure against flow for the pressure relief valves after they have started discharging; data on the exact weight of the antenna on each of the three feet; 8) measurement of the circumferential motion of the runner during

VITTORIO CASTELLI, PH.D.

repeated passes of the antenna feet.

All such data should be referred to me for conclusions on the pattern of the last failure and for understanding of the true relation between the design and the prototype and thus establishing a prediction of future behavior.

The most important recommendation is to issue and enforce a strict set of rules concerning experimentation with and modification of the bearing system. A concise, an clear, and thorough manual should be written and made available. Above all, a single person should be well instructed and made responsible for the system. Since it is impossible to construct an idiot-proof system, the next best solution is to keep the idiots away from it!

Vittorio Castelli

VITTORIO CASTELLI, PH.D.

Mr Horace Phillips
Jet Propulsion Laboratory
Pasadena, California.

Dear Horace,

This letter is to clarify a point on my report on the visit to the 210' AZ-EL Antenna at Goldstone. Some misunderstanding may result from my denomination of right and left from pads. I intended right and left from the point of view of an observer to whom the antenna is pointing when in its horizon position. For an observer located at the azimuth axis these denominations would obviously be reversed. I hope you will make this point clear to all concerned and that I have not misled you in my conclusions.

Best Regards

Vittorio Castelli

DSIF 14

06 ANTENNA

- HYDROSTATIC BEARING REPAIR AND REPORT
- PLUG RUNNER HOSE

JPL CONT 950650 C/O #38

SCOPE: Repair hydrostatic bearing and resume antenna erection.Engr: HP Phillips X4743Proc: HE McDonald X2600WW Lord X3946C/C: JP Frey X3946Rohr: GM Faughender 714-422-7112 X553Rucker: HJ Bates 415-653-52212 16:00 Bearing pads scored runner Don Ramsey X371 DH McClure X3543 Rohr/Rucker/JPL Field inspection of damage5 Plot of 4 Sep MG Newsted Runner data WD Merrick X2385

HPP

6 C/Vista Mtg - Engr Question list & "No fix till answers"6 Relief valve tests at Rohr8 Metal spray runner fix disapproved9 Removed final pad for inspection

DR

10 Runner weld procedure (draft)

CJ McCaul X3756

Manos

10 Site Mtg10 Interim field hydrostatic tests17 First Rohr recovery schedule - Reliner welder qualified17 V Castelli to Keystone Engrg & site18 Checked pad flatness at Keystone

JPF

21 Start runner welding23 Pads back on site24 Good field hyd tests completed27 JPL/Rohr review of entire subject at Rohr28 C/O Req for welded runner plugs

WDM/HA Davis X3020

29 TWX advice of C/Order #38 signature

RH Bartlett X3078

29 C/Vista Responsibility Mtg: Rohr VS Rucker29 Cracks found in pad post welds

JPF

1 Pasa Mtg Rohr/Rucker - Defective H/P filters admitted4 Mtg FE McCreery/Woodward5 Rohr TLX 1 Excellent minutes of 1 Oct Mtg

GMF

6 Pad chem analysis shows 47 pts carbon unweldable7 Found collapsed H/P filters7 Filters returned to purolator8 Agreed bolted plate fix for post weld cracks8 Mtg post welding disapproved

Rohr } Sch.
Rucker } MTD.
P. Potter

WD, MERRICK
H.P. PHILLIPS
J.P. FREY
W.W. LORD
H.E. McDONALD

CC:

SEPTEMBER 1965

OCT 65

B. 06

11

11

12

12

Pads welded.

Sch and tech fix mtg at GTS.

HHP

Pad post fix approved.

Pad holes plugged.

D. Hester X368

15 25

Pad post repair complete.

15 25

18

Start trough installation.

18

19 26

Start pad installation.

19

Start oil cond.

21 28

C. pad installation.

21

C el brg repair.

22 1

Alidade down on pads.

5

OCT

25

28

JPL report (draft) complete.

HHP

29

Rohr report (draft) complete

cc:

3

1

1

C troughs.

2

Fill hyd brg.

4

First az rotation.

5

Hyd brg checked & operational

5

Rohr report at JPL.

5

Centrifuge on site

5

NOV

4

8

8

Hi-pressure filters on site

11

Magnetic wipers on site

15

APPENDIX IV

Film Heights on Right Front Pad Measured 30 July 65

First Test
Last Test

.0085 in
.0068

.010 in
.0085

.007 in
.006

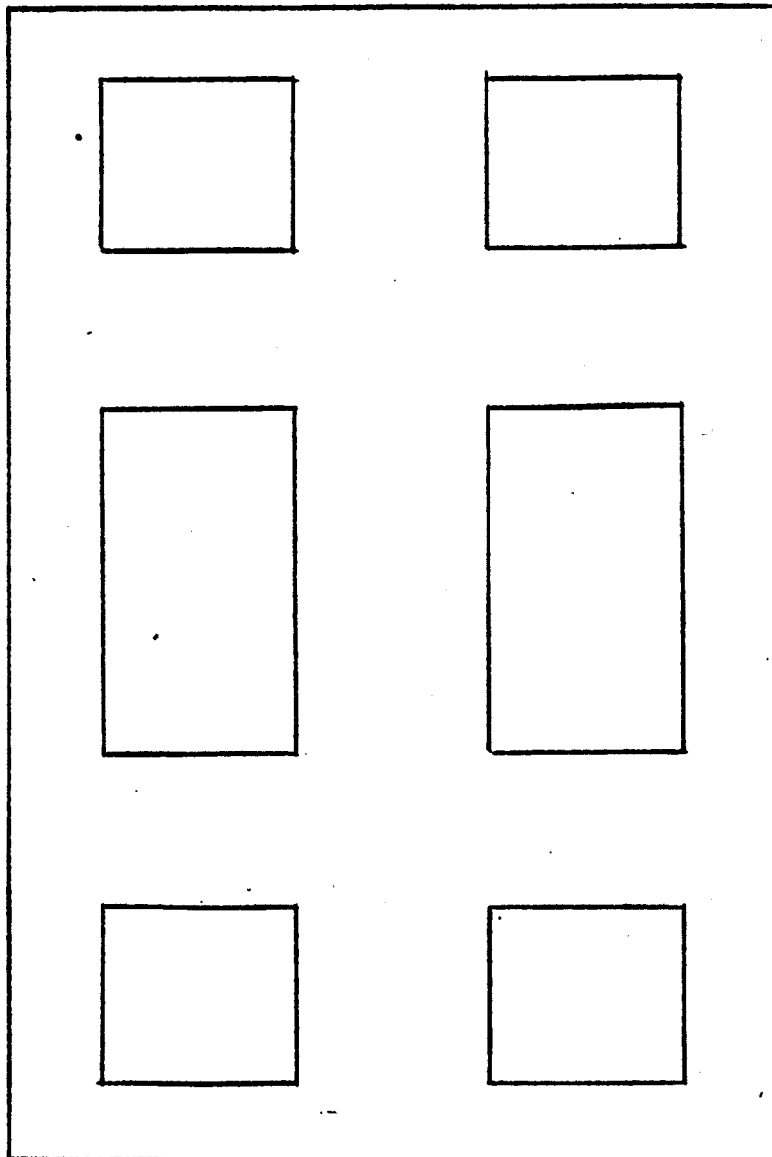
.008
.0055

.008
.0058

.0088
.006

.0105
.0085

.0092
.0068



APPENDIX V

List of Photographs

Figure No.	Title	Negative Number
4	Right Front Pad Before Removal	332 7684A
5	Pad Being Removed	332 7687B
6	Gall Marks Under Right Front Pad	332 7699A
7	Scratches in Runner at Four O'Clock Position	332 7698A
8	Scratches in Runner at Five O'Clock Position	332 7698B
9	Scratches in Runner at Seven O'Clock Position	332 7699B
10	Scratches in Runner at Ten O'Clock Position	332 7701A
11	Gall Marks in Runner at Ten O'Clock Position	332 7701B
12	Scratches in Runner at Eleven O'Clock Position	332 7702A
13	Typical Gall Mark at a Bolt Hole	332 7702B
14	Bottom Face of Right Front Pad	332 7597A
15	Closeup of Right Front Pad Damage	332 7597B
16	Bottom Face of Rear Pad	332 7693
17	Closeup of Rear Pad Damage	332 7674A
18	Bottom Face of Front Left Pad	332 7697A
19	Closeup of Left Front Pad	332 7697B
20	Millwright Chipping Runner Damage Area	332 7720A
21	Millwright Grinding Runner Damage Area	332 7719A
22	Millwright Welding Runner Damage Area	332 7731B
23	Millwright Grinding Welds on Runner	332 7748B
24	Final Grinding on Runner	332 7748A

RICHFIELD OIL CORPORATION

WATSON REFINERY

LABORATORY CERTIFICATE

Form 144 15M 9-56
Print. in U.S.A.

SAMPLE OF

EAGLE OIL MEDIUM HEAVY R&O

FILE NO. 352.5

FROM

Jet Propulsion Lab
4800 Oak Grove Dr. - Pasadena, Calif.
Oil sample from 210' Antenna Hydrostatic
Bearing

DATE September 16, 1963

DATE TESTED

INSTRUCTIONS OF

Mr. M. H. Sperling (4)

REFERENCE NO. Analysis No. W-2015

	<u>Large Sample</u>	<u>Small Sample*</u>
Viscosity @ 100°F, SUS	661	
Viscosity @ 210°F, SUS	71.2	
Viscosity Index	94.3	
Water by Distillation, %	0.03	
Acid No.	0.14	0.03
Strong Acid No.		0.01**
Base No.	0.06	
Corrosion @ 210°F, 3 hrs.	1b	
Ash, %	0.001	
E. S. Analysis, % of Sample		
Barium	Nil	
Calcium	Nil	
Phosphorus	Nil	
Zinc	Nil	

*Sample about 1/3 water. No additional tests were made.

**Less than.

YBK:hs

Original Signed By

C. T. Brown

BY



Figure 4. Right Front Pad Before Removal

9-7-65

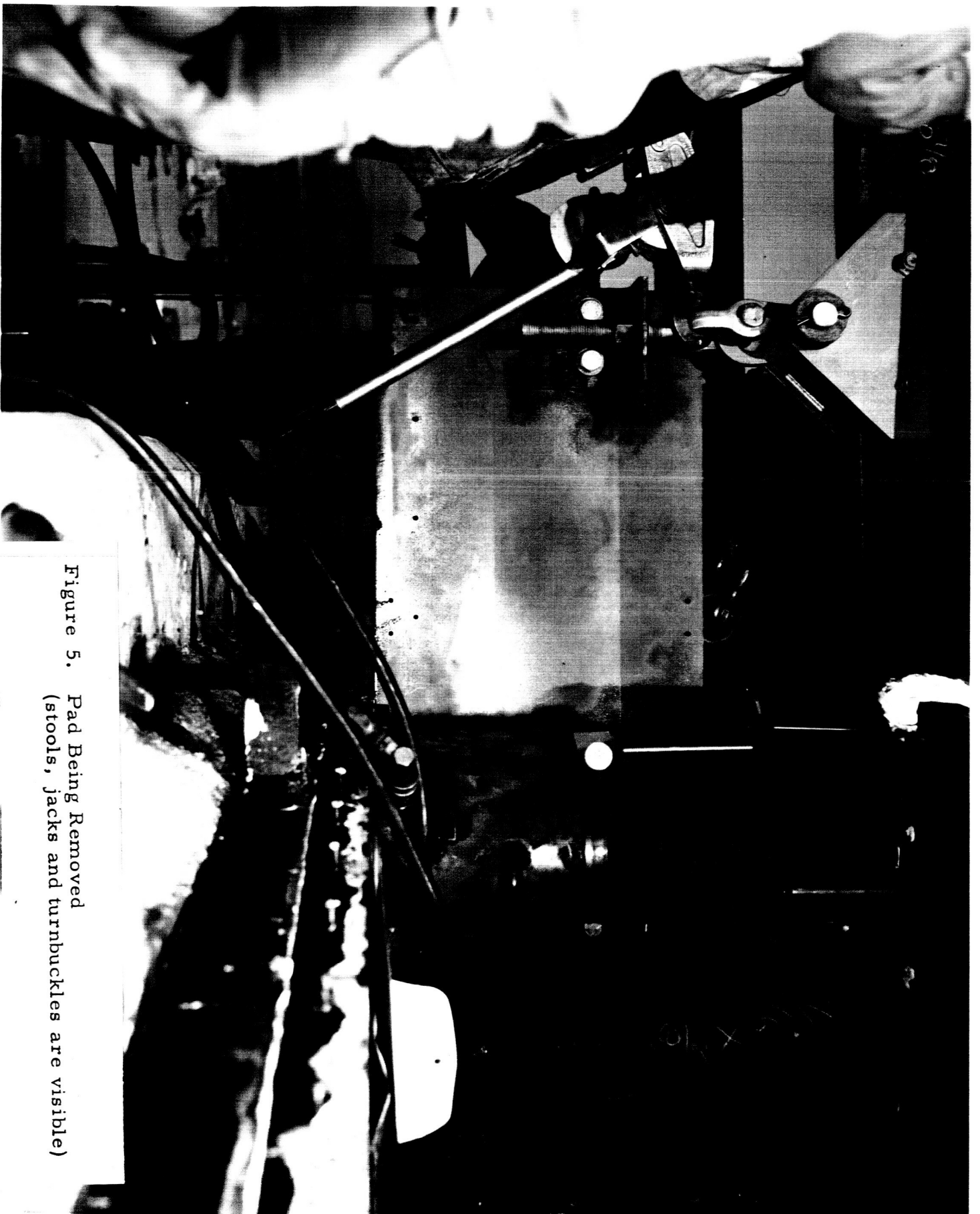


Figure 5. Pad Being Removed
(stools, jacks and turnbuckles are visible)

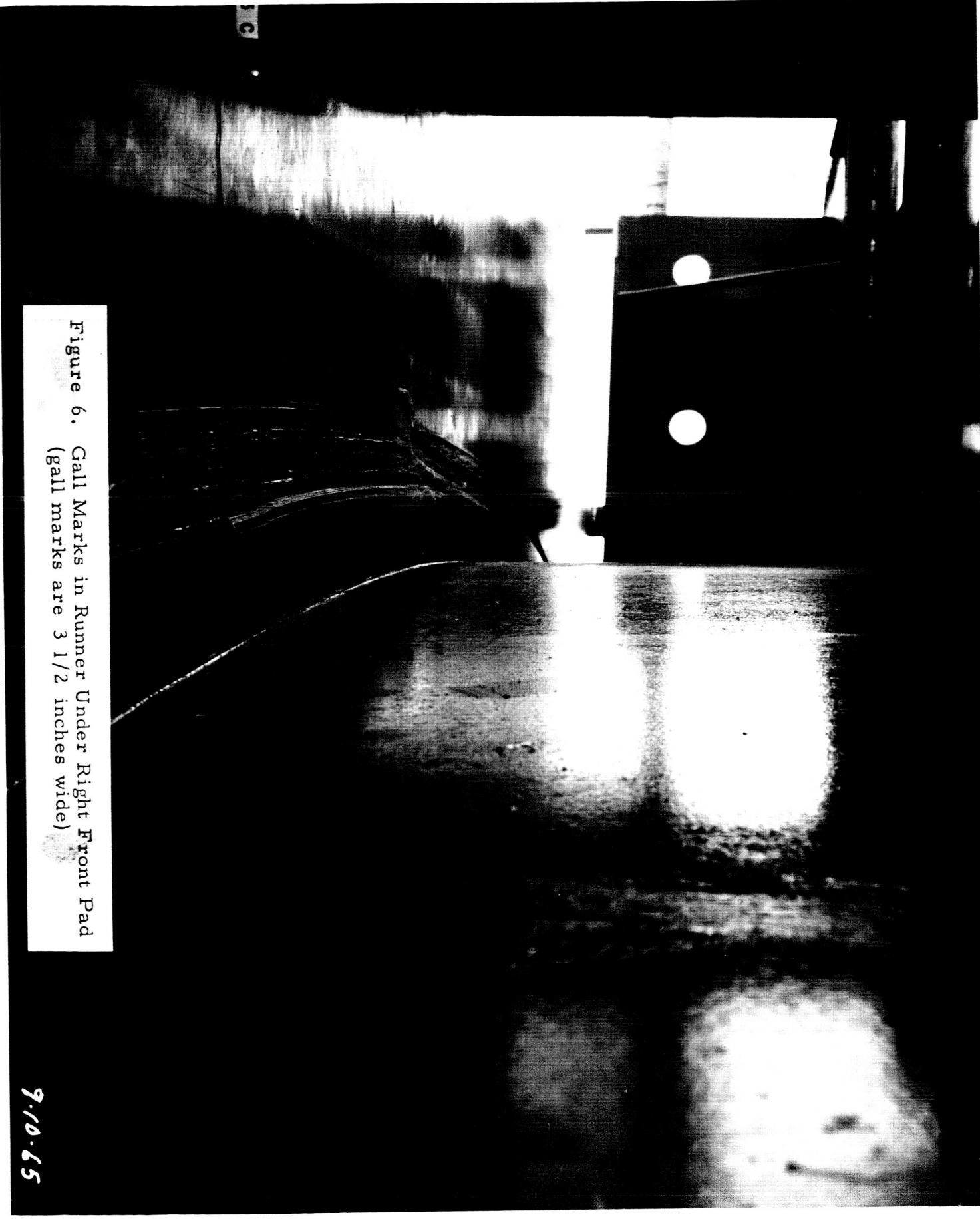


Figure 6. Gall Marks in Runner Under Right Front Pad
(gall marks are 3 1/2 inches wide)

9.10.65



SK 134585 A

Figure 7. Scratches in Runner at Four O'Clock Position
(scale is approximately full size)



SK 134585 B

Figure 8. Scratches in Runner at Five O'Clock Position
(scale is approximately full size; original machining
grooves are less than .001 inches high)

9.10.65

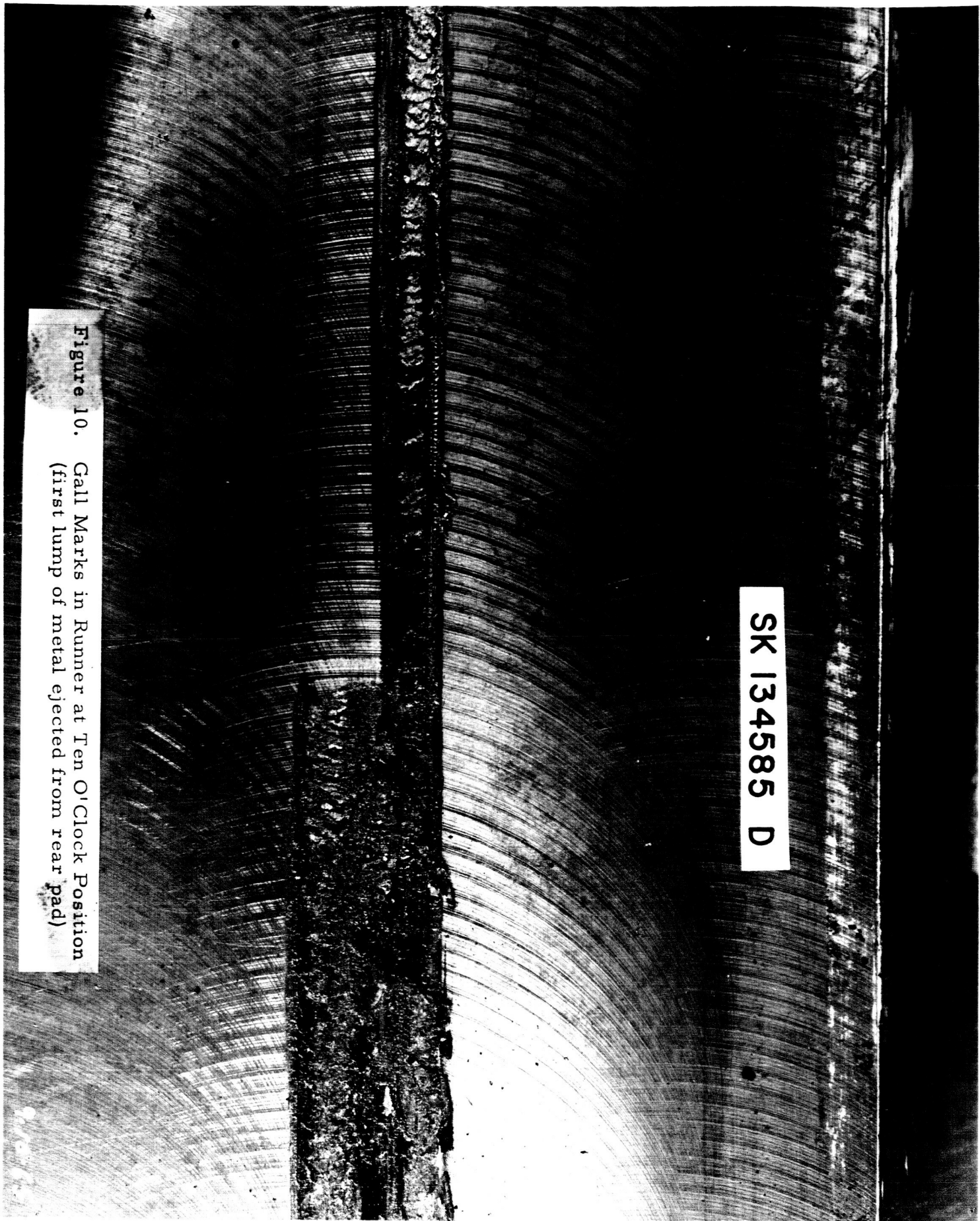
SK 134585 C

Figure 9. Gall Marks in Runner at Seven O'Clock Position
(scale is approximately full size)

9-10-65

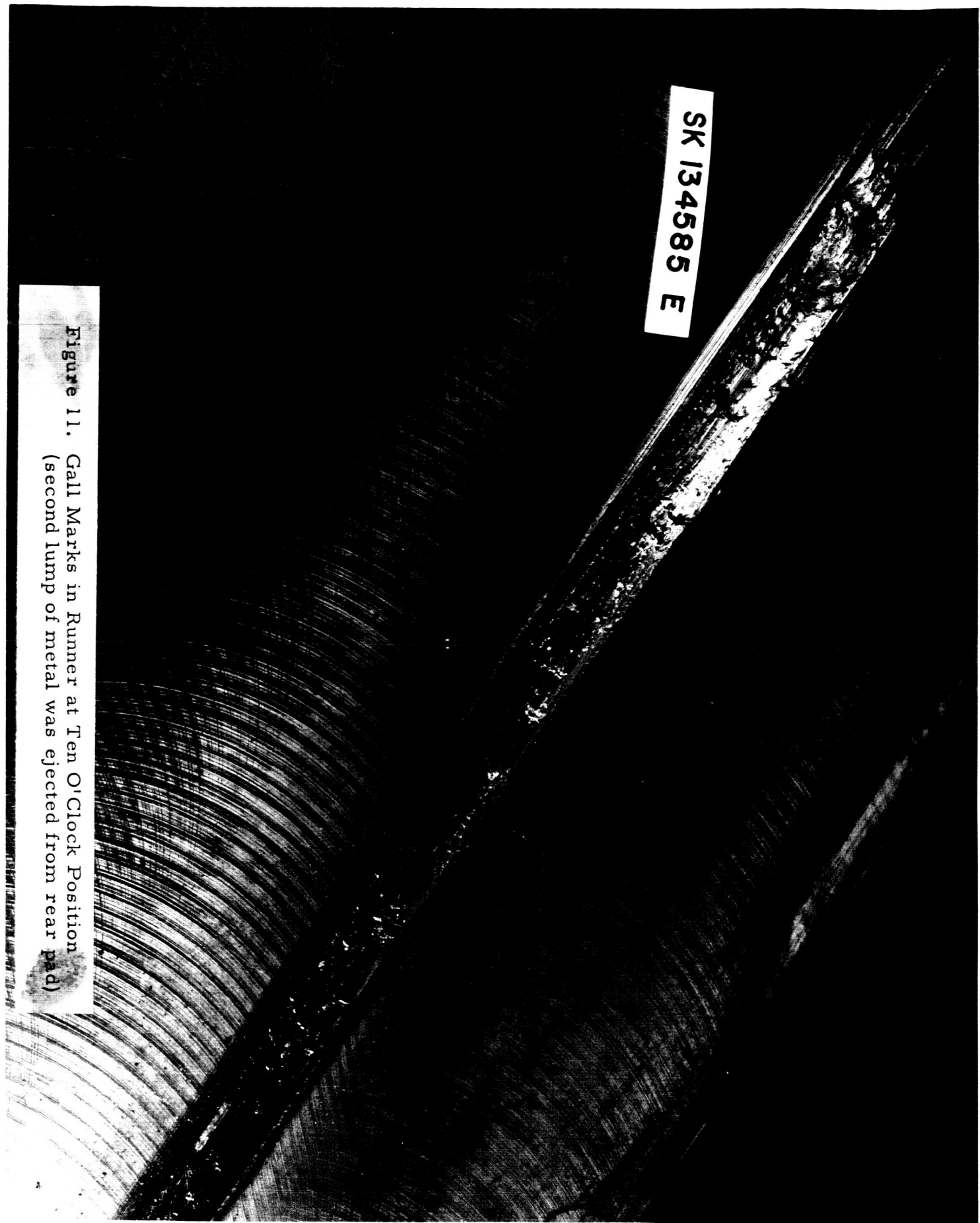
SK 134585 D

Figure 10. Call Marks in Runner at Ten O'Clock Position
(first lump of metal ejected from rear pad)



SK 134585 E

Figure 11. Gall Marks in Runner at Ten O'Clock Position
(second lump of metal was ejected from rear pad)



SK 134585 F

Figure 12. Runner Scratches at Eleven O'Clock Position
(this was the clockwise limit of damage)

9-10-63

SK 134585 G

Figure 13. Typical Gall Mark at Bolt Hole Showing Direction of Motion

9-10-65



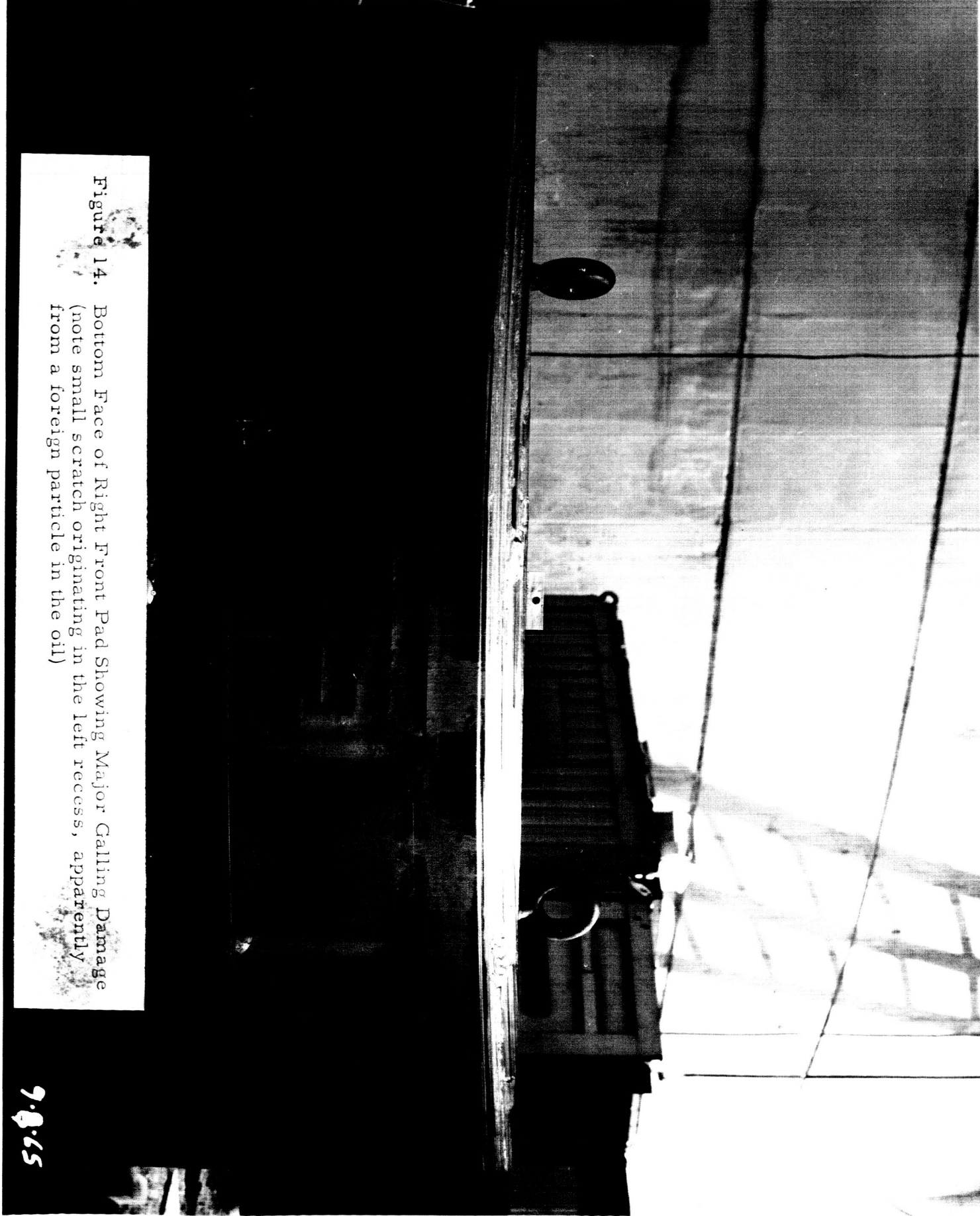


Figure 14. Bottom Face of Right Front Pad Showing Major Galling Damage
(note small scratch originating in the left recess, apparently
from a foreign particle in the oil)



Figure 15. Closeup of Major Damaged Area in Bottom Face of Right Front Pad

9.9.65

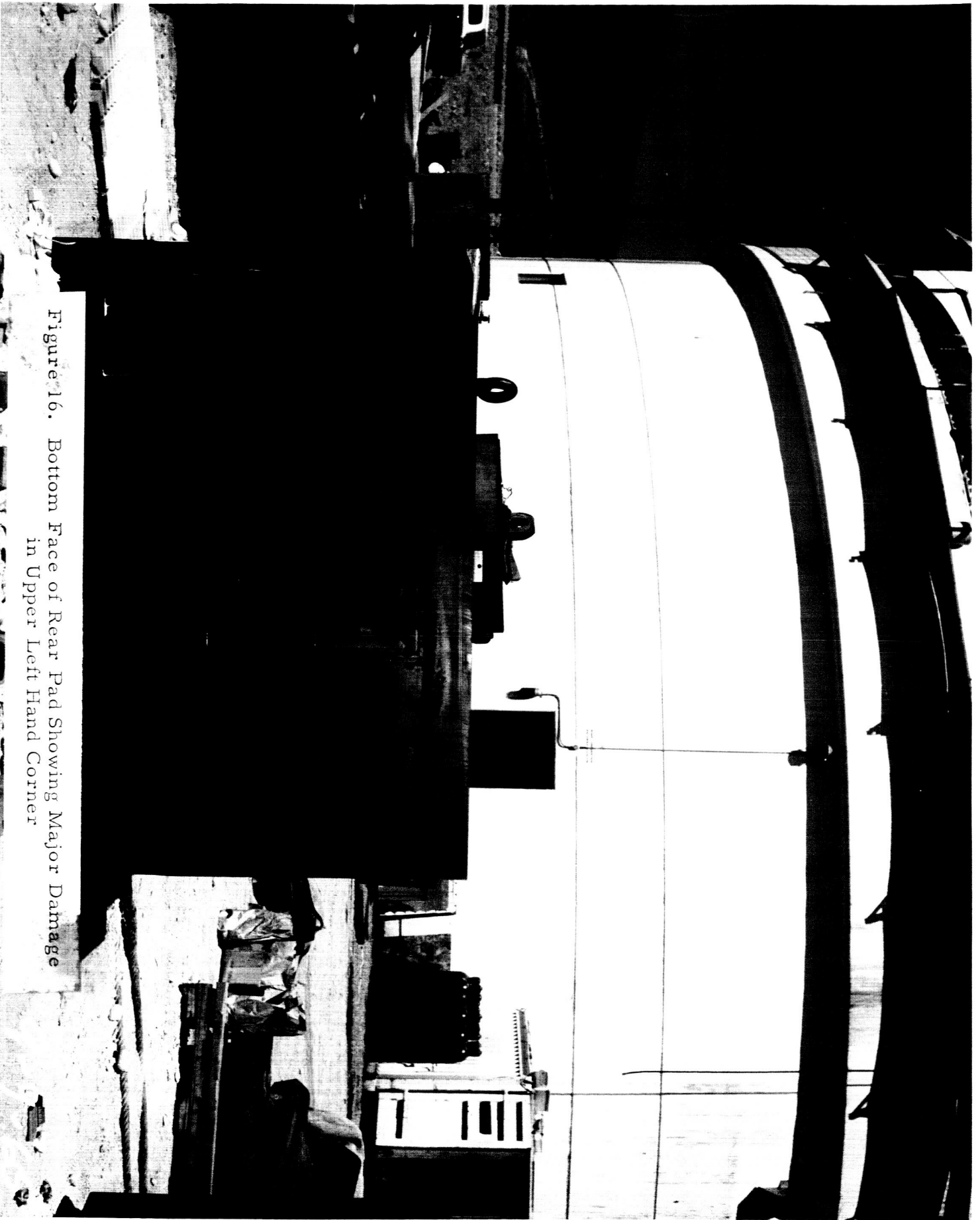


Figure 16. Bottom Face of Rear Pad Showing Major Damage
in Upper Left Hand Corner

Figure 17. Closeup of Major Damage Area of Rear Pad

9-9-60

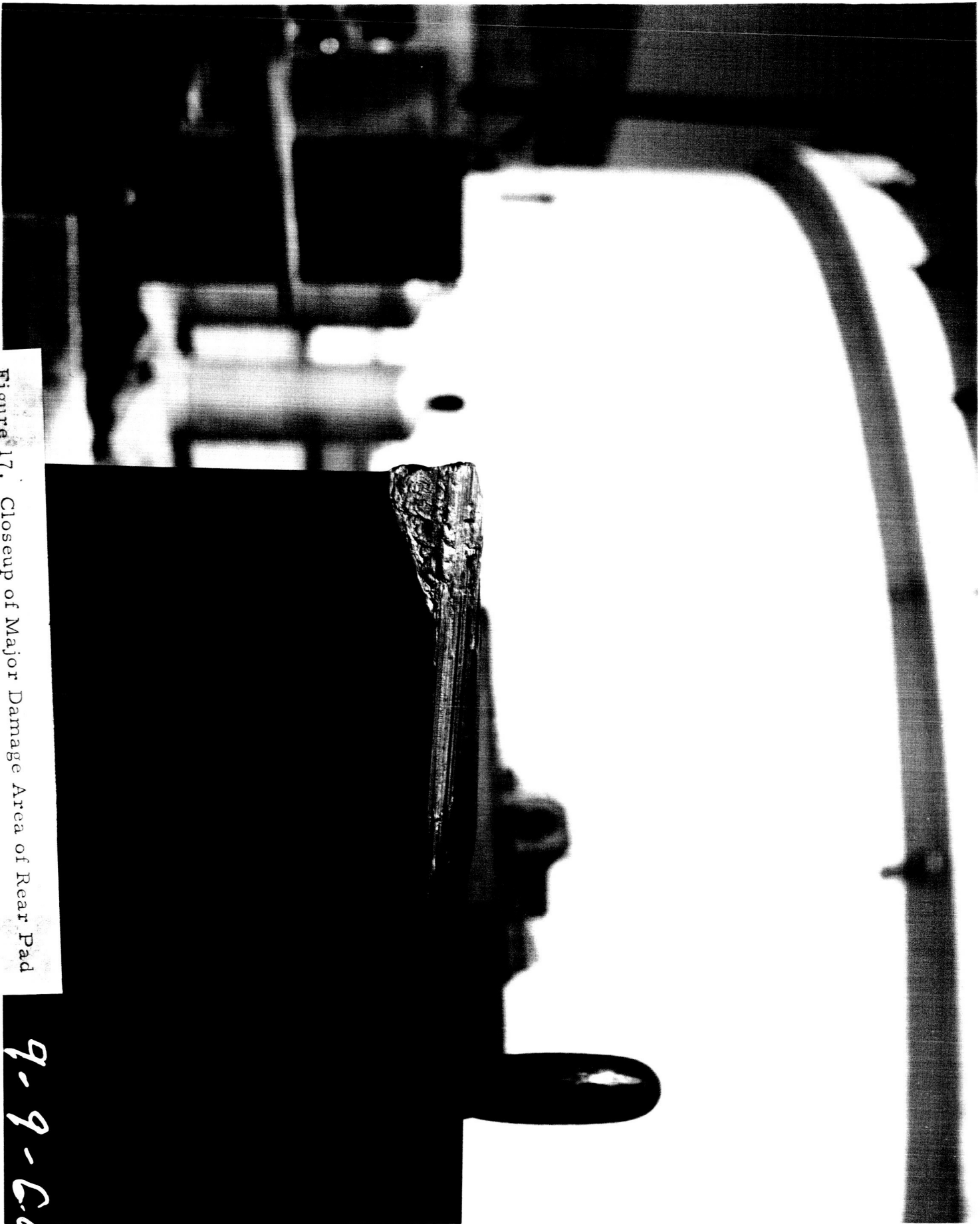




Figure 18.

Bottom Face of Left Front Pad
(note small scratches originating in upper left recess
and in center probe recess, probably from foreign particles)

9-10-65

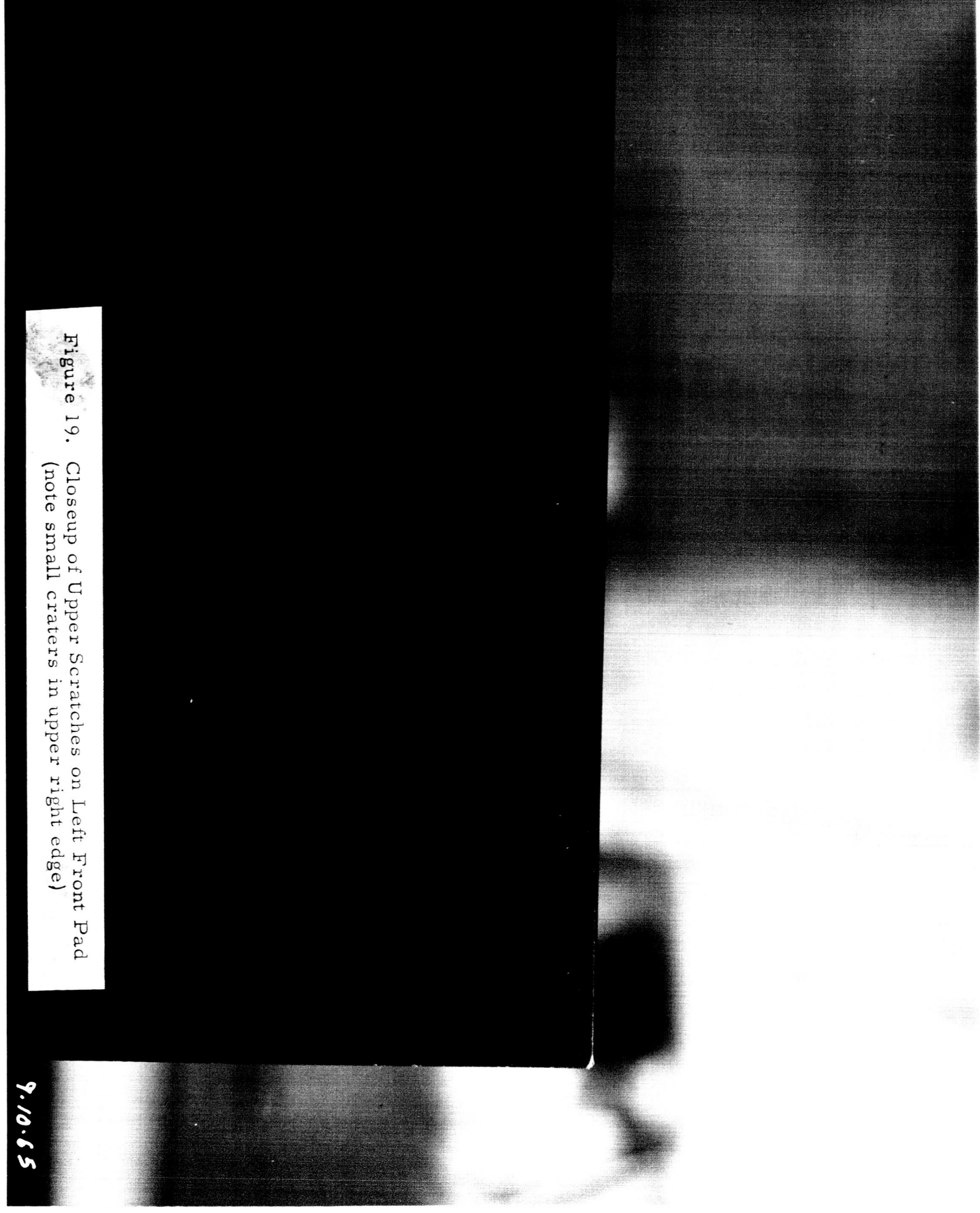


Figure 19. Closeup of Upper Scratches on Left Front Pad
(note small craters in upper right edge)




Figure 20. Millwright Chipping Loose Metal From Damaged Area of Runner

9.20.64



Figure 21. Millwright Grounding Out Damaged Area in Runner
Preparatory to Welding

9.21.65

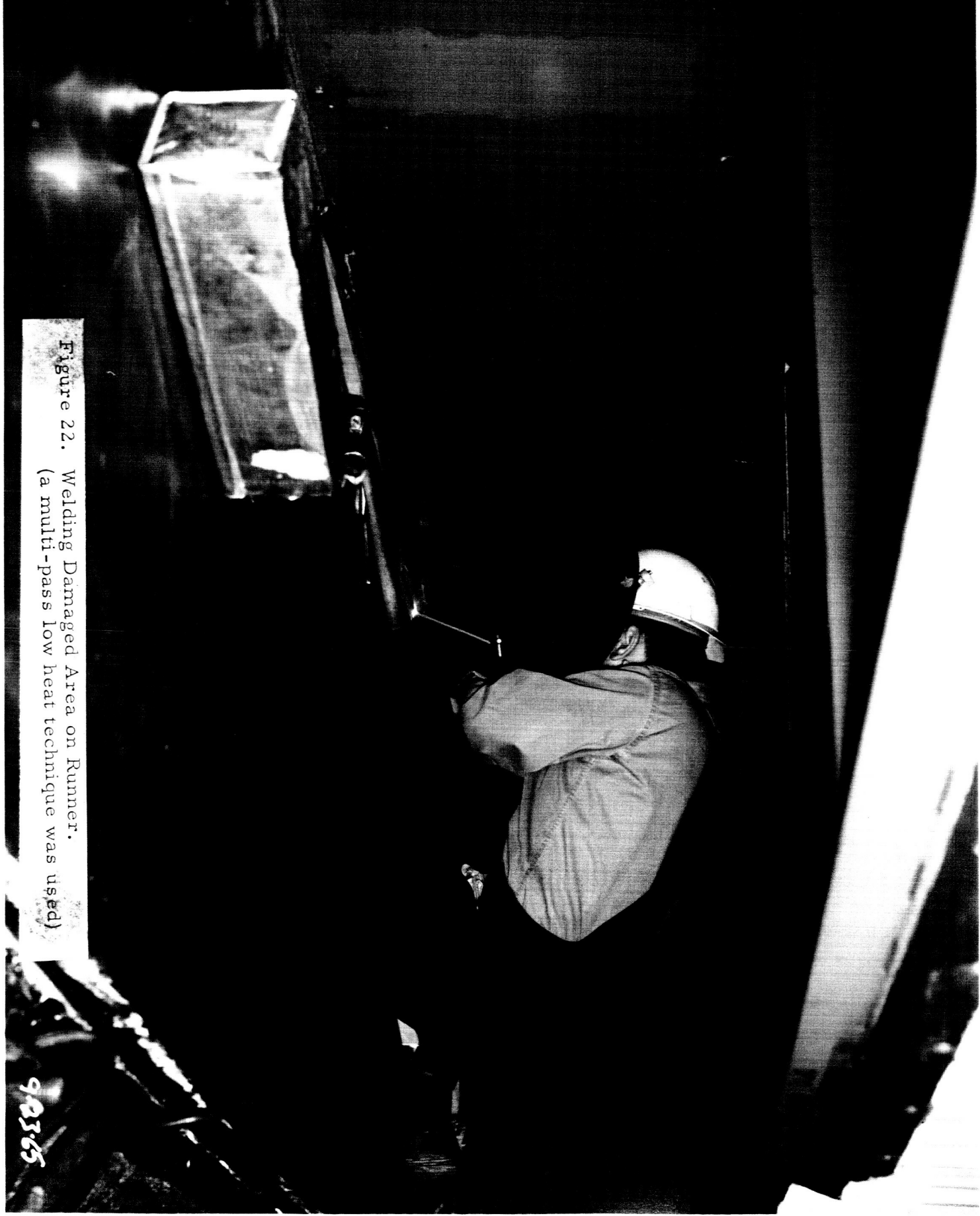
A high-contrast, black and white photograph showing a welder in profile, wearing a helmet and protective gear. The welder is positioned in the lower right, working on a large, dark metal structure. A bright, rectangular light source, possibly a welding torch or a light fixture, is visible in the upper left, casting a strong glow. The overall scene is dark, emphasizing the welder and the light source.

Figure 22. Welding Damaged Area on Runner.
(a multi-pass low heat technique was used)

Figure 23. Hand Grinding Welds on Runner



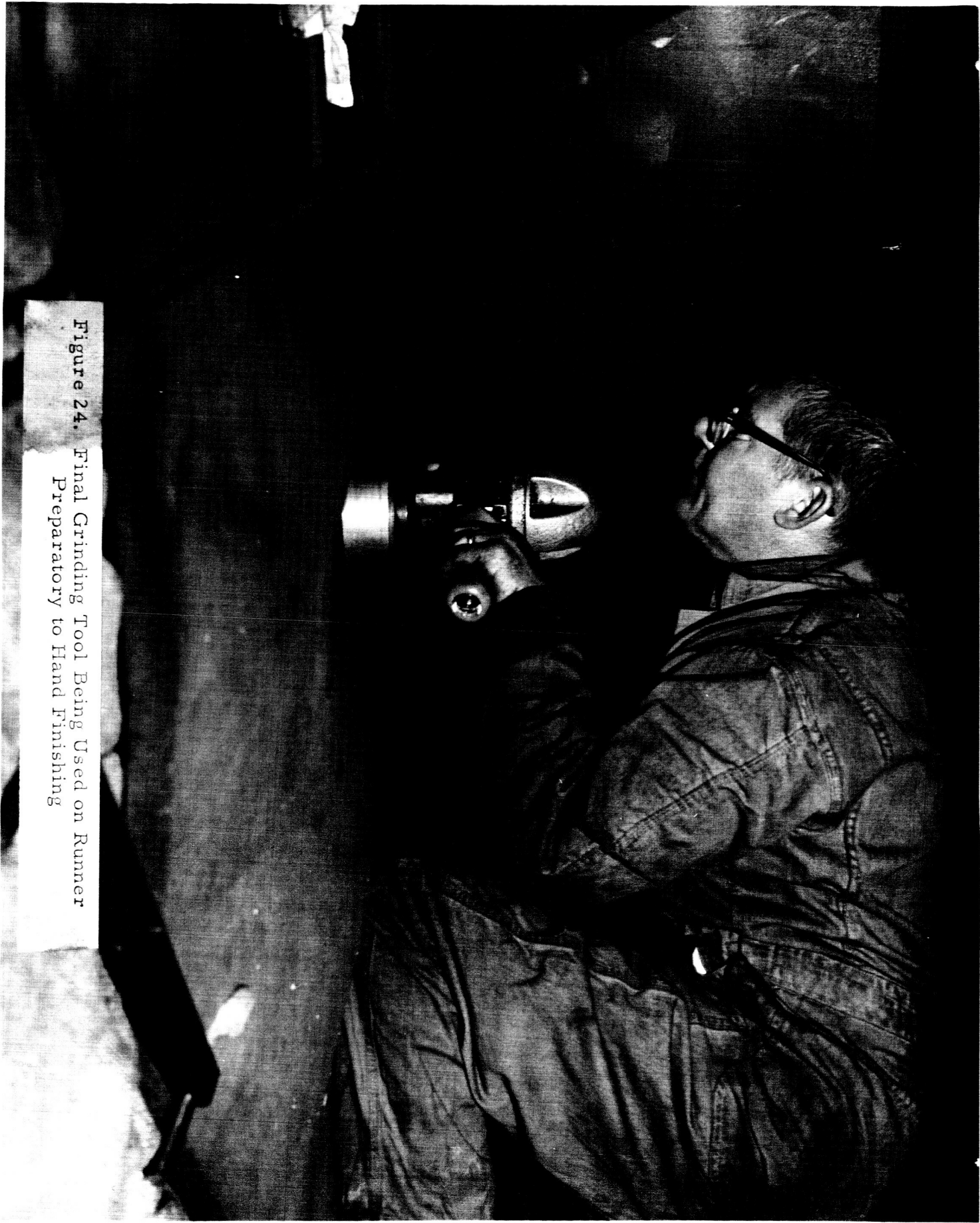


Figure 24. Final Grinding Tool Being Used on Runner
Preparatory to Hand Finishing

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- II. OPERATION OF HYDROSTATIC BEARING
- III. STATEMENT OF OPERATIONAL STATUS OF HYDROSTATIC BEARING
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- V. INVESTIGATIONS
REPAIR OF DAMAGED PARTS
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- VI. CONCLUSION
- VII. RECOMMENDATIONS
- VIII. APPENDIX
 - A) DR. CASTELLI'S REPORT
 - B) REPORT ON THE ON-SITE HYDRAULIC TESTING
 - C) REPORT ON ROHR IN HOUSE TESTING
 - D) WELDING PROCEDURE
 - E) ROHR LABORATORY REPORT
 - F) JPL DWG. #SK-134585

ENGINEERING REPORT

REPORT NO. 420-ER8

ROHR CORPORATION
ANTENNA DIVISION

TITLE: **ENGINEERING REPORT ON HYDROSTATIC BEARING DAMAGE**

Prepared by C. Bainbridge *Bainbridge* Date 10-28-65

Approved by A. M. Isber *A. M. Isber* Date 10-28-65

Approved by G. M. Faughender *G. M. Faughender* Date 10-29-65

Approved by S. A. Rocci *S. A. Rocci* Date 10-28-65

Revision	By	Approved	Date

RELEASED
ALL CHANGES MUST
BE RECORDED

- I. The 210-foot diameter Advanced Antenna System employs a hydrostatic bearing to support the deadloads, windloads and seismic loads of the rotating parts of the antenna and transfer these loads into the foundation.

The basic elements of the hydrostatic bearing system are:

- A. A steel runner, 80 feet in diameter, 44 inches wide, 5 inches thick.
- B. A trough around the runner which forms a reservoir for the 5000 gallons of hydraulic fluid (SAE 30 oil, 550 SSU).
- C. Three steel pads, each 40 inches wide, 60 inches long and 20 inches thick, positioned equidistant one from the other. Each pad has six recesses on the pad to runner face which are pressurized for lift off and operation of the antenna.
- D. A hydraulic supply system which draws oil from the reservoir by means of two high volume low pressure pumps used to precharge the inlet port of the high pressure system.
- E. The high pressure systems, one for each pad, delivers oil under pressure to each recess to create the force to lift the antenna and after lift off, delivers sufficient volume of oil to maintain the stiffness of the bearing.

- II. The operational requirements of the hydrostatic bearing are:

- A. The hydraulic system must be capable of lifting a static load in excess of the deadload, windload and seismic load of the antenna. The combination of these loads in the worst operating condition is 1,800,000 lbs. at each bearing pad.

- B. After lift off, the system must be capable of delivering 7.5 GPM per recess in order to maintain bearing design stiffness and film height. The nominal film height is .010 inches.

Tests of the system and its components establish that the above conditions cannot only be met but exceeded.

III. Statement of Operational Status of Hydrostatic Bearing

The hydrostatic bearing was known to be operational in December 1964 and apparently remained so until 4:30 P.M., September 2, 1965, when damage was ascertained; see Appendix F JPL Dwg. #SK-134585. Subsequently, a variety of investigations, inspections and analyses were conducted to determine the cause(s) and to establish the repair and corrective measures to prevent any future occurrence.

IV. Tests Conducted

These tests included:

- A. Weight Check of Antenna - by using hydraulic jacks at each bearing point and computing weight as a function of pressure and jack ram area. This test verified the design weight of 1,700,000 lbs. per pad.
- B. Oil Viscosity Check - this check verified the oil was in good condition and proper viscosity. This test was arranged by JPL and the report is in their possession.

- C. The oil was drained from the reservoir and all residue and chips created by the failure were analyzed for chemical composition. The Rohr lab report shows no foreign material in the system, all chips found in the bearing were determined to be A-36 material which is the same material as pads and runner. Reference Rohr Lab Report #MP-322, Appendix E.
- D. An extensive check of the hydraulic system component by component and as a system was conducted on-site to establish operating characteristics. All components tested met or exceeded specification requirements. Reference Appendix, Exhibit "B".

V. Investigations Conducted

It was established through a thorough investigation that the relief valves (No. 23 as shown on Dwg. F04371) and the shut-off valves (No. 24) in the high pressure system had been incorrectly set.

The major cause of the damage was the fact that the relief valves had been adjusted to 900 psi average at the high pressure skid in lines leading to the corner recesses and 1200 psi in lines leading to the center recesses of the pads. These settings corresponded to the pressures observed on the gauges during lift-off.

It was ascertained beyond reasonable doubt that the readjustment of relief valves occurred on August 19 and 20, 1965. This conclusion is established from the following facts:

- A. The reservoir and hydraulic system was drained as of June 9, 1965. The runner was inspected and found in excellent condition.

- B. From initial operation, December 4, 1964 through August 18, 1965, relief valve settings were at 1500 psi (well above the lift-off and working pressures). Both the start-up instructions, and the testimony of the hydrostatic bearing program manager substantiate these settings.
- C. August 19 and 20, 1965, a subcontractor technician worked on the high pressure skids, and admittedly reset the relief valves to the 900 psi - 1200 psi pattern described earlier.

It was subsequent to the last action above, that damage was incurred. Moreover, tests conducted at the site established that the shut-off valves (downstream of the relief valves) were nearly closed during rotations performed by Rohr subsequent to August 20, 1965, which combined with the flow diversion at the relief valve, further limited pressure build-up under the pads and caused the damage.

On September 3, 1965, a meeting was held at Goldstone to inspect the damage and determine proper methods of repairing and preventative measures against any future occurrences.

1. Extent of Damage and Repair

The runner was damaged in varying degrees from a scratch to gouges approximately 2 1/4 inches wide and .040" deep. The extensive damage or gouging was over approximately 180° of the runner.

Reference JPL Dwg. SK-134585.

Three methods of repairing the runner were discussed:

- A. An Epoxy Fill
- B. Metal Spray
- C. Welding

Method "A" was discarded due to possibility of poor bonding of the epoxy to the steel runner.

Method "B" was discarded, since bonding of metal spray to runner was considered too risky.

Method "C" was chosen because of the high degree of assurance all concerned had for the eventual outcome.

A specification for the repair and inspection of the repair of the runner was developed. Reference - Welding Specification, Appendix, Exhibit "D".

From September 3, 1965 to September 7, 1965, preparations for removing the pads were made. On September 8, 1965, Pad #1 (right front) was removed and found to be badly galled with two high spots protruding beyond the original surface. The high spots were removed and analyzed and found to be runner or pad material which had become fused to the pad.

Subsequently, Pads #2 (left front) and #3 (rear) were removed and found to be damaged in a similar manner, but to a lesser degree. Photographs were taken of all pads and runner and are in the hands of both Rohr and JPL.

Repairing the pads required machining the damaged surfaces and rephosphatizing of the machined surfaces. Due to the small amount of metal removed (approximately .010-.020"), no height adjustment by shimming is required as this would effect the alignment of the elevation bearings only and they have not been final aligned.

On September 3, 1965, all relief valves on the high pressure Skid #1 and 3 were sealed to preserve the settings for future tests. Five of six shut-off valves on #2 were sealed (all others had been moved in the interim). Eight relief valves, six from #3 high pressure skid and two from #1 high pressure skid and one shut off valve from #3 high pressure skid were removed and taken to Rohr for functional testing.

This test confirmed the abnormally low setting of the relief valves sufficient to definitely cause the damage.

The pressures shown in the following table were as checked at Rohr on September 6, 1965, reference memo of I. Dagan to R. D. Hall dated 9-9-65.

<u>Position</u>	<u>Pressure In Lbs.</u>
1	715
2	1,080
3	960
4	900
5	1,100
6	830

The results established a pattern of relief valve settings at 900 psi and 1200 psi as mentioned earlier.

Later tests run on the same components at Goldstone show some variances from the above stated pressures, but not significantly different to

change the end results. Reference - On-Site Engineering Report #420-ER9, Appendix B.

VI. Conclusion

The hydrostatic bearing system is completely adequate to perform its function under the operating conditions defined in JPL Document EPD #5 - providing relief valves are set at a safe margin to allow lift-off pressures at the pad, and yet fulfilling their primary function, which is to protect the high pressure pumps which are rated at 5000 psi. Accordingly, relief valves should be set at 2500 psi minimum with a recommendation that they be set at 3750 psi. Further shut-off valves should be fully open to assure full flow to the pads.

This position is supported by Dr. V. Castelli of Franklin Institute and Columbia University who did the theoretical design analysis of this bearing. Reference Dr. Castelli's report, Appendix, Exhibit "A". Quoting from Dr. Castelli's report - "An operational bearing system need not only be able to supply lubricant at the pressure needed to carry the load at steady state, but also should raise the feeding pressure when the load increases and the film thickness decreases. This feature is called stiffness and makes the bearing a stable system since it can oppose all perturbing forces. The stiffness of a constant flow system is due to the fact the feeding pressure can rise as much as needed to push a given amount of fluid through the clearance in a given time. This happens regardless of load; but if the feeding pressure is limited by a pressure relief valve, the system stiffness becomes zero any time the feeding pressure needs to become higher than the valve setting." End of quote.

^A
VII. Recommendations for Averting Reoccurrence of Damage in the Future

Rohr will exercise the following corrective or testing steps immediately:

- A. A complete system field check as soon as the repairs are completed and submit a written report on the results.
- B. Seal all adjustments to prevent future tampering. This includes relief valves, shut-off valves, etc.
- C. Rohr/Rucker will issue complete instructions on the operation of the hydrostatic bearing and will hold formal instruction sessions for all personnel charged with the operation of the antenna to make sure they are properly instructed and qualified to make adjustments if required.
- D. A complete check-off list indicating every point to be checked on start up and points to be checked during operation of the antenna and insist on these sheets being used until Rohr's liability is ended and Rohr strongly recommends continuance of this practice after formal turn over to JPL.

The original check-off list signed off by all cognizant engineers (JPL, Rohr and Rucker) may be filed on site, but a copy of this must be furnished to this office for our records. No rotation will be permitted without this document being completed.

- E. To implement this check out, Rohr/Rucker will clearly mark tolerance bands on all gages indicating safe operating pressures.

- F. Upgrade system monitoring and interlock provisions.
- G. Rohr will monitor all pressure sensing devices for accuracy while on site and strongly urges JPL to continue such a program after Rohr leaves the site. These checks must be recorded on the article checked and remain as a permanent record.

APPENDIX
SECTION VIII

EXHIBIT "B"

INTRODUCTION

This work summarizes the results of the hydrostatic bearing power unit tests run September 23 and 24, 1965, with representatives from Rohr, Rucker and JPL present. Information as to certain characteristics of the major components of the high pressure system was accumulated and recorded. The data collected was assimilated thoroughly, reviewed, and indicates that damage to the hydrostatic bearing can be tied directly to the relief valve settings, and to the nearly closed position of the downstream shut-off valves.

SUMMARY

The field testing of the high pressure hydraulic system definitely proves the damage was due to maladjustments and not system failure.

The system demands the following:

1. 1100-1200 psi lift-off pressure; 900 psi (approximate) working pressure.
2. A minimum of 7.5 GPM flow per recess. (Operating condition)

The data taken during the field tests and summarized in this report definitely proves the system capabilities are in excess of the requirements.

DISCUSSION

The purpose for testing of the hydrostatic bearing high pressure hydraulic system was to field test the system for any component deficiency of failure.

To perform this test, the Rucker Company supplied a functional test stand and a portable supercharge unit with this supercharge unit connected to a high pressure hydraulic skid (3 skids per system, 6 pumping units per skid. Reference Rucker Drawing #04371).

The following tests were performed:

1. Relief valves were checked in the as is condition to verify checks made at Rohr.
2. The relief valves were then set to relieve at 3000 psi and checked for reset pressure level. Reference Figure 3.
3. Check the flow rate of the pump with varying relief pressure settings from 200 psi to 3000 psi using a Fisher & Porter Turbine Flowmeter. For results, see Figure 2.

Additional testing was done on Skid #3 (rear position) as follows:

- a. With the shut off valve in the closed position and progressively opening the valve to one turn open, the pressure drop across the shut off valve was measured and from this data, Pressure Drop Curve, Figure 5, was developed. From one turn open to full open was an extrapolation of the data taken.

- b. Two relief valves were tested for resetting with varying relief pressures from 500 psi to 4000 psi, the resetting pressures in all ranges was less than 1%. Reference Figure 3 and 4.
- c. Connecting the complete hydraulic line from the pump to and including the check valve at the pad (see Figure 1) with the shut off valve full open, the pressure drop at the pad was measured at 175 psi.

This test was run with a nut behind the spring on the filter by pass valve which increased the spring tension forcing more oil to feed through the filter and increasing the pressure drop across the filter.

4. This was a repetition of test #3 without the nut behind the by-pass valve, the pressure drop to the pad was then measured at 150 psi.

After completion of the tests, all relief valves were set at 3000 psi (subject to increase after review at Rohr) and the shut off valves were left full open.

BY _____ DATE _____
 CH'KD _____ DATE _____

PAGE 1
 TITLE _____

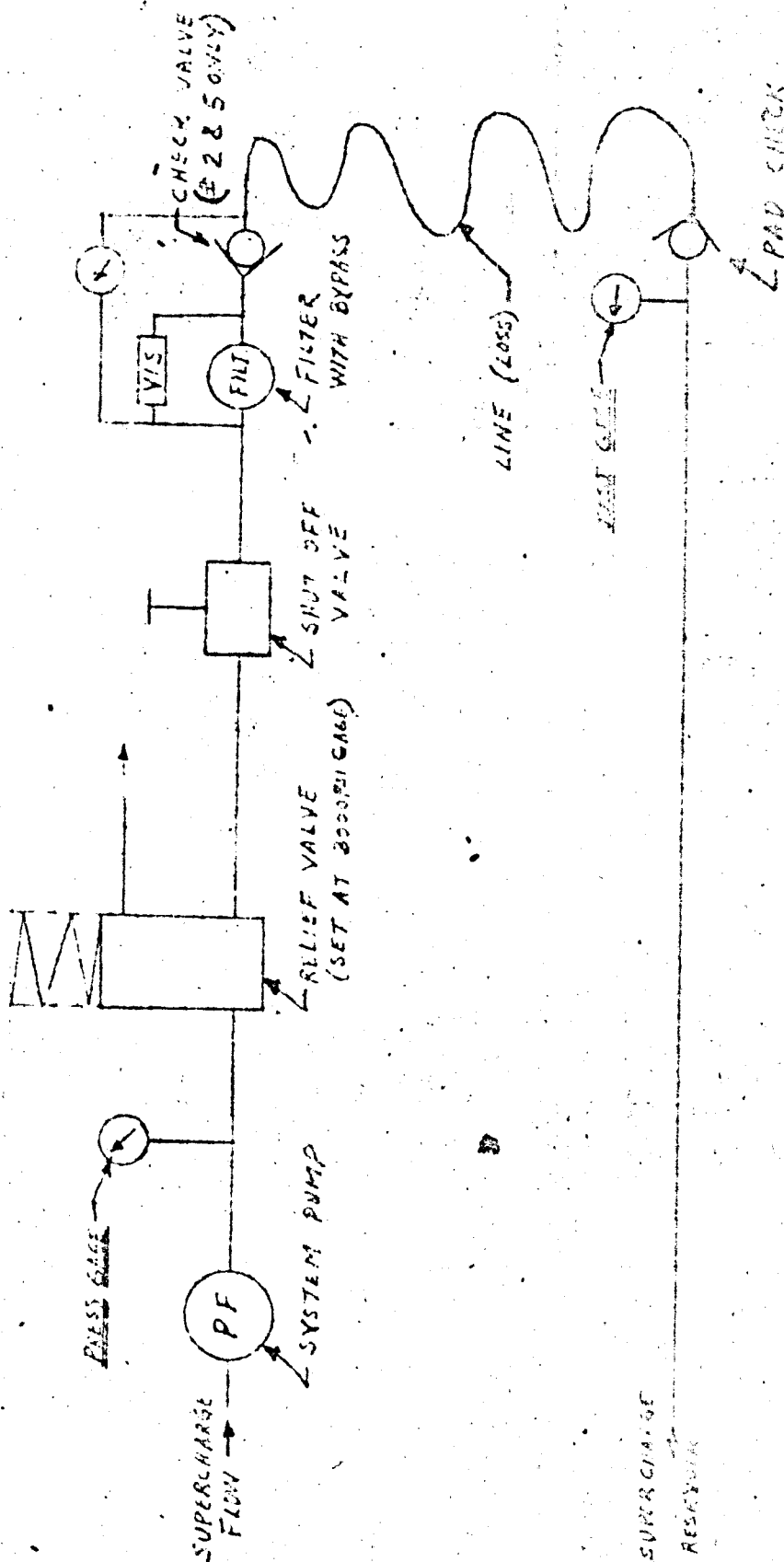


FIGURE 1 SYSTEM LOSS

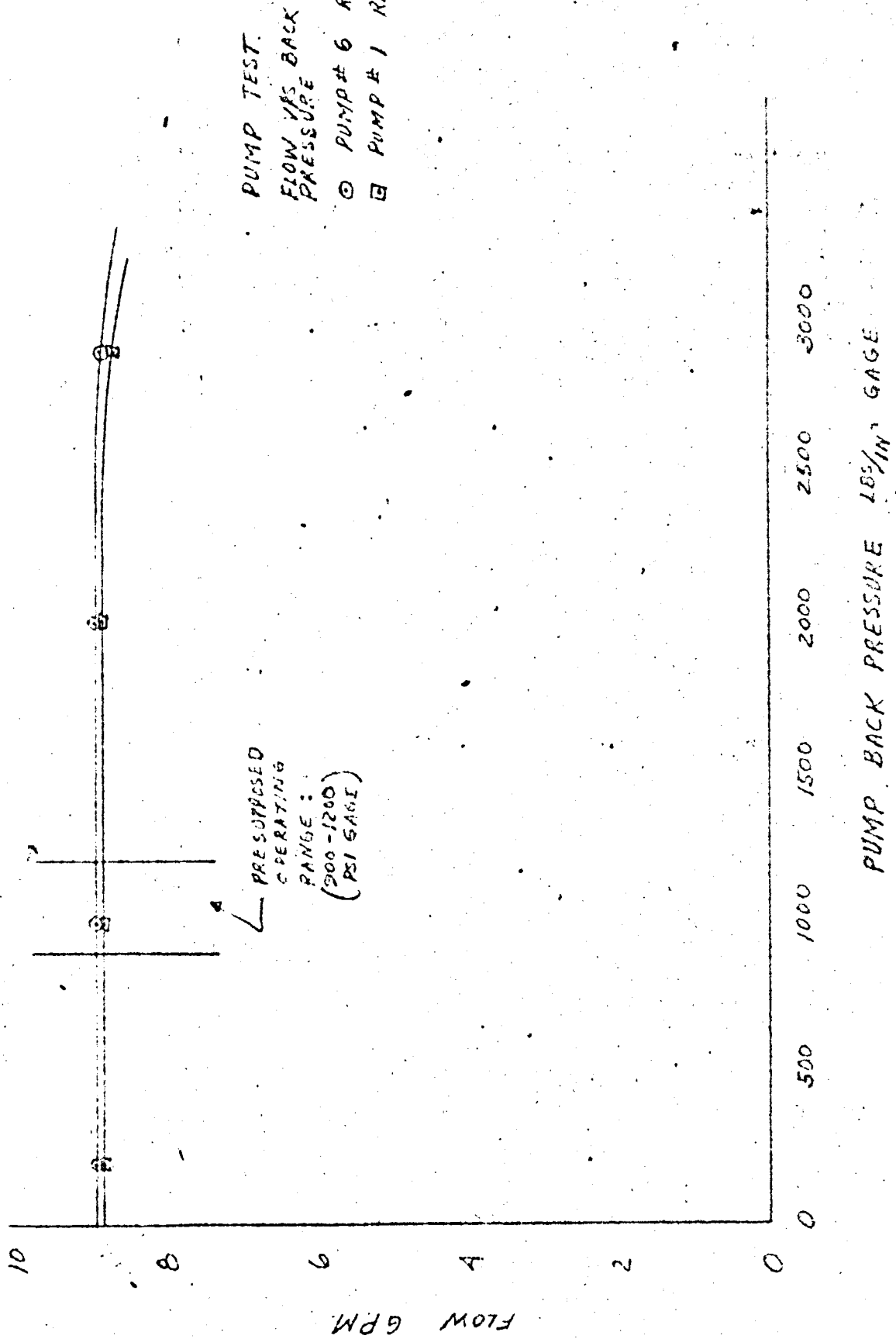


FIGURE 2

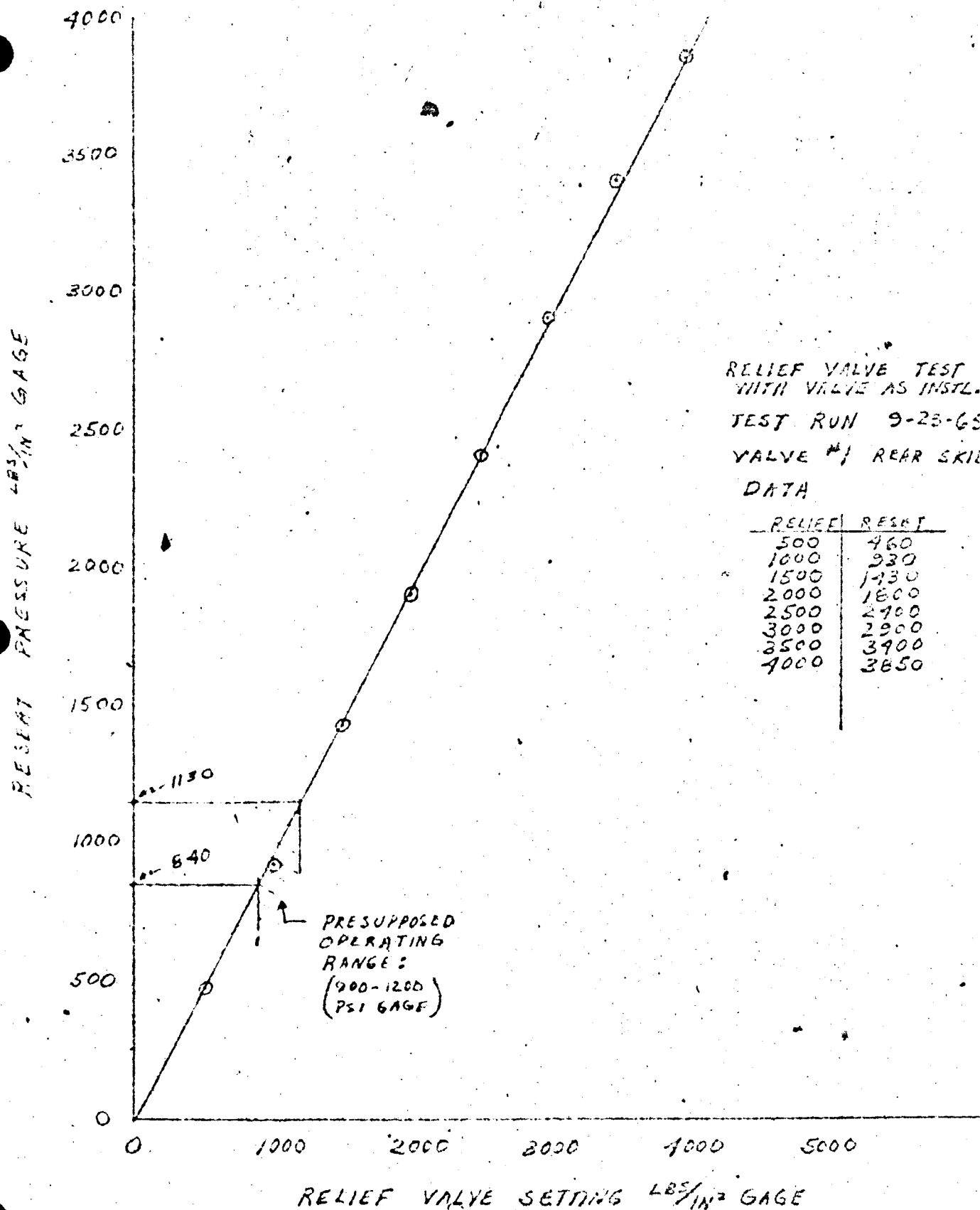


FIGURE 3

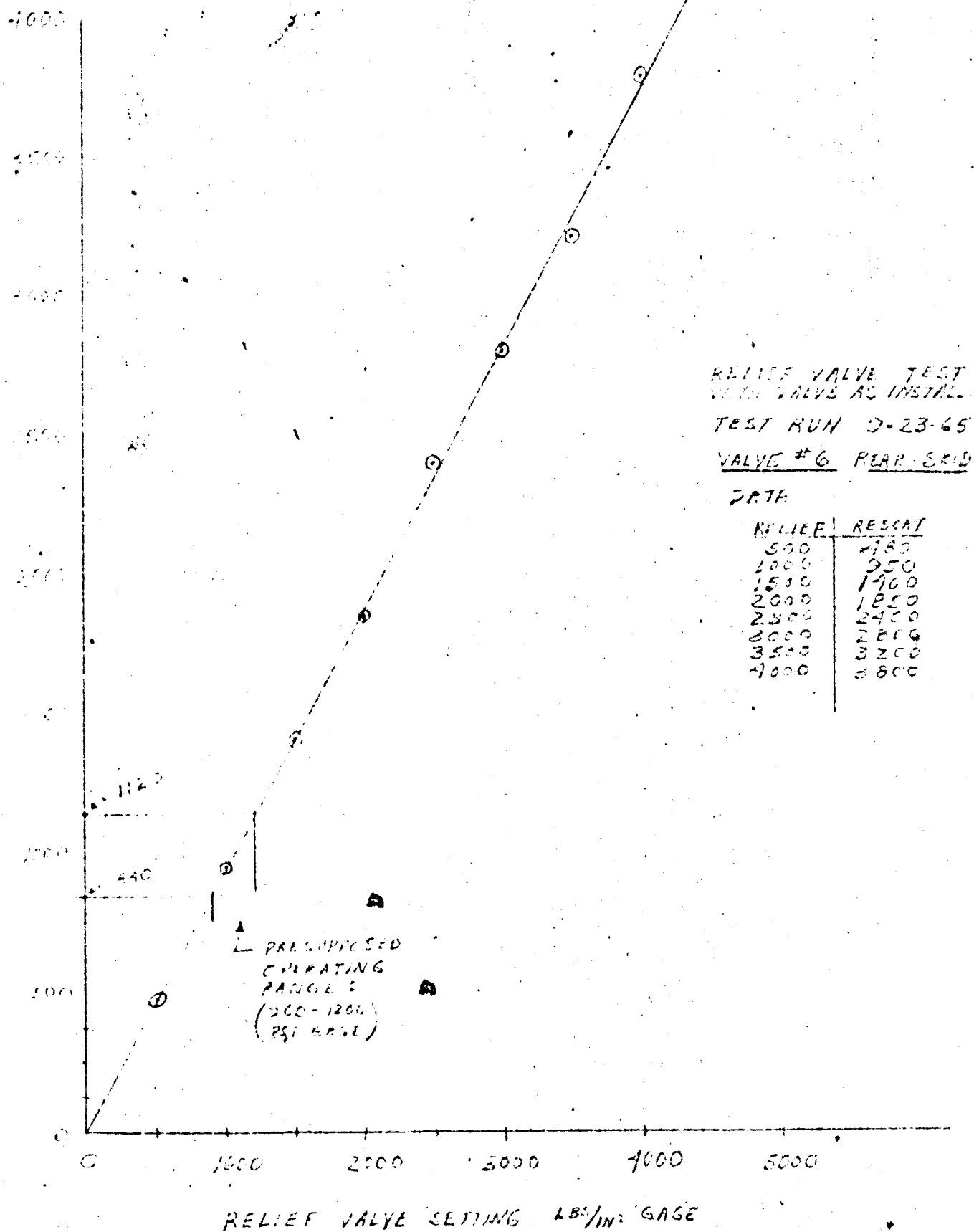


FIGURE 4

SHUT OFF VALVE TEST
VALVE #2 REAR SKID

DATA:

VALVE POS.	PRES. PSIG.
CLOSED	3000 (RELIEF SETTING)
1/4 TURN	800
1/2 TURN	400
3/4 TURN	300
FULL TURN	250
FULL OPEN	20 (ESTIMATED)

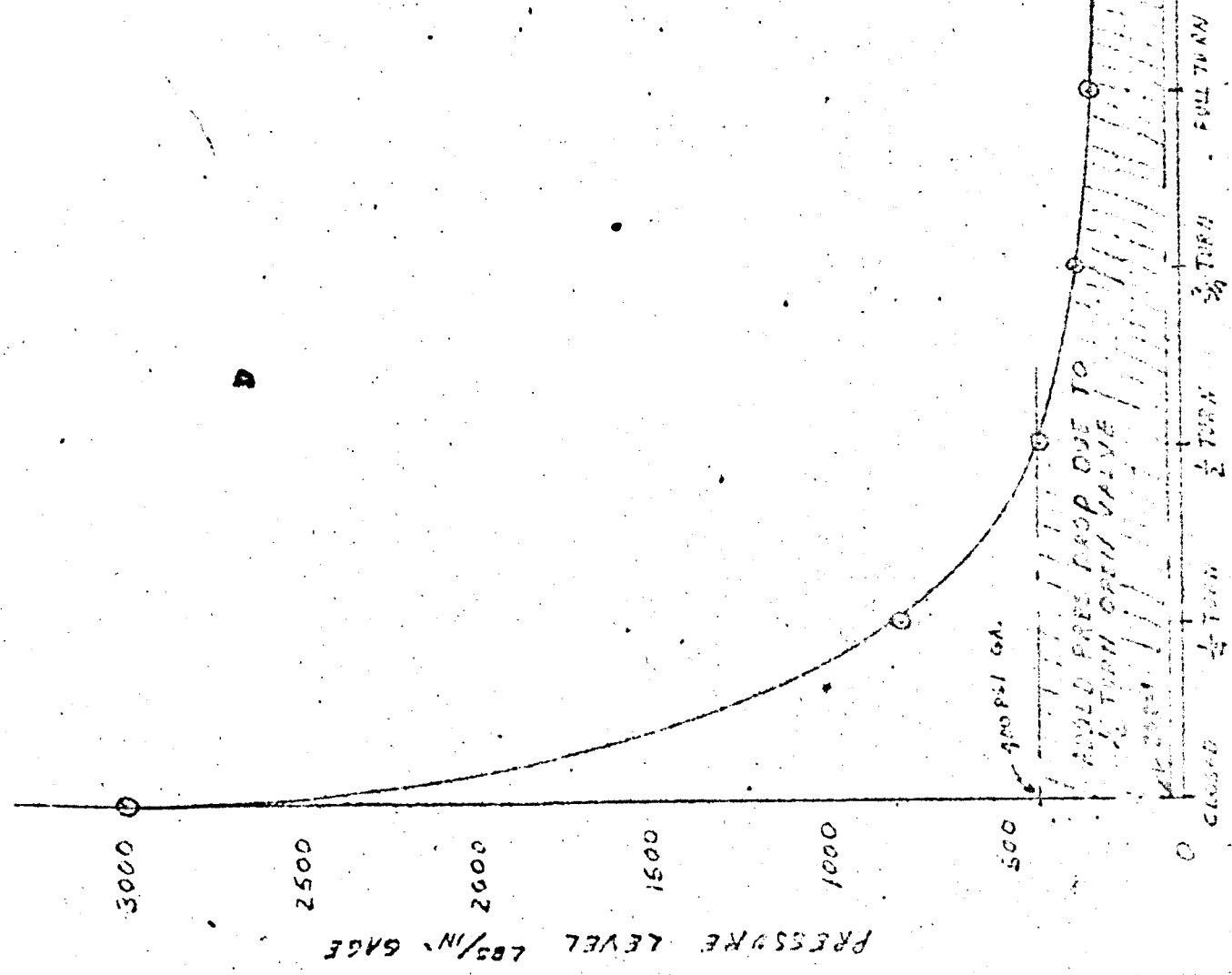


FIGURE 5.

BY FI OAKLEY DATE 2-28-65

CHG. NO. _____ DATE _____

PAGE

6

TITLE HYDROSTATIC
BEARING TEST

SUMMARY PRESSURE LEVEL DATA

SKID #2 (LEFT FRONT) AS IS CONDITION

CAVIT OR UNIT (PUMP PRESS)	1. RELIEF VALVE SETTING* LB/IN ² GA	2. PRESS. LEVEL (GAGE READING) VS SHUT OFF VALVE AS IS CONDITION	3. EST. PRESS. LEVEL WITH SHUT OFF VALVE FULL OPEN LB/IN ²	4 (2-3) NET ΔP CAUSED BY VALVE BEING IN NEAR CLOSED POSITION	5 (1-7 - LINE LOSS OF 20 PSI) EST. PRESS. AVAIL AT PAD LB/IN ² GA
1	300	300	125	175	580
6	300	370	125	215	540
10	300	250	125	125	630
11	1650	200	125	75	830
5	1200	220	140 ⁶	20	1010
2	200	—	140 ⁸	—	—

- * REPALENTS PRESSURE AT PAD FOR STATIC (NO FLOW) LIFT C/L
- SEE DIAGRAM BELOW (WITH LINE LOSS EXCLUDED)
 - LINE CONTAINS A CHECK VALVE ADJACENT TO FILTER UNIT

SAMPLE CALC (EST LINE LOSS)

ASSUME 30' OF EQUIVALENT $\frac{3}{4}$ " PIPE SCH 160 10-619
WITH FLOW RATE 8.8 GPM 30 SAE 550230 OIL
FROM HEAD LOSS CHART

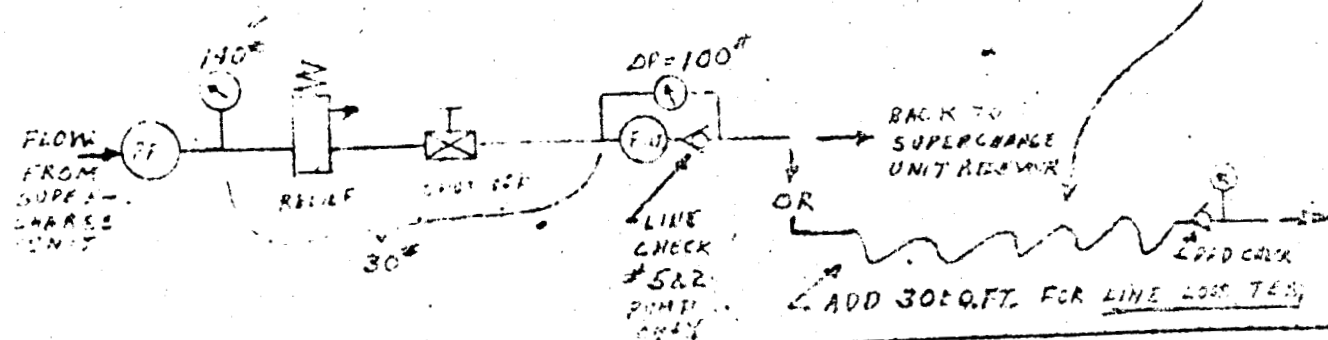
$$\text{LOSS} = \frac{175}{100'} \text{ PIPE}$$

$$\text{FOR 30'} \quad \text{LOSS} = \frac{175}{100} \times 30' \times \frac{62.4 \times .90}{144} = 20.5'$$

SPECIFIC GRAVITY

SAY 20[#]/IN²

TEST SET UP



ROHR CORPORATION
Chula Vista, California

EXHIBIT **L**

Date: September 9, 1965

In reply refer to:

To: R. D. Hall
From: I. Dagan
Subject: 210' Antenna Relief Valve - Tests

Reference:

Per request, 8 each of the subject valves were tested by Functional Test on September 6, 1965, as follows:

Test Condition:

- (a) Test Media: MIL-O-7808
- (b) Flow Rate: 7.5 GPM
- (c) Gauge #P-1120: 0-2000 PSI

Test Results:

No.	Valve I. P.	Relief Pressure Setting	Oil Temp.
1.	Position #5 - Pad #3	1100 PSI	110°F.
2.	Position #6 - Pad #3	880 PSI	105°F.
3.	Position #3 - Pad #3	960 PSI	108°F.
4.	Position #1 - Pad #3	715 PSI	112°F.
5.	Position #2 - Pad #3	1080 PSI	118°F.
6.	Position #4 - Pad #3	900 PSI	118°F.
7.**	Position #2 - Pad #2	1240 PSI *	122°F.

* Valve reseats at 720 PSI.

** Unit seal became broken. Seal was re-established with glyptol.

8.	Position #1 - Pad #2	880 PSI	121°F.
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One hand controlled valve was checked by applying 1500 PSI to valve in closed position. While pressure was applied, valve was opened one quarter ($\frac{1}{4}$) turn. This caused pressure to drop to 380 PSI with seven (7) GPM flow.

Prior to testing, the pressure gauge #P-1120 was checked for calibration against a dead weight tester traceable to the National Bureau of Standards.

Please advise if any further details are desired.

ROHR CORPORATION *EXHIBIT 'D'*
Chula Vista, California

Date: September 9, 1965

In reply refer to: RE/0891-ACM

Revision A - 9/13/65

To: R. A. Petersen
From: A. C. Manos *ACM*
Subject: Repairing of the Hydrostatic Bearing Runner

Reference: J. P. L. 210' Antenna

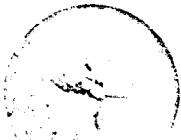
Following is the recommended operations to rework the hydrostatic bearing runner. This procedure was mutually agreed to, by C. McCaul of J.P.L. and A. C. Manos of Rohr.

1. Hand clean bearing surface with acetone. Remove all oil from weld area.
2. Hand chisel to remove any loose metal from gouged area.
3. Set dial indicators prior to welding, record and check reading during and after welding of one six foot sections.
4. Use 3/32 and 1/8" dia. #7018 electrodes, larger electrodes shall not be used.
5. All welding shall be accomplished with stringer beads only.
6. Each weld (one weld rod constitutes one weld) shall have a minimum of 30" centers or as specified by the cognizant Weld Engineer.
7. Spot check using D.P.M. for external defects.
8. The initial welding shall be accomplished under the direction of a Weld Engineer, and all welding shall be monitored by Inspection.
9. It is recommended that only one welder begin this procedure until one six foot section has been completed.
10. Quality Standards:
Welding shall be accomplished to represent the highest commercial quality workmanship.

External Defects:

The visible surface of all welds shall be free of cracks. Surface defects such as porosity, undercut or voids are acceptable if the maximum extent of the defect does not exceed one of the following limits.

- 10.1 Porosity or voids 1/8" diameter .030 deep.
- 10.2 Undercut .030 deep 1/8" wide 3"



SECRET

TECHNICAL INFORMATION REQUEST

SERIAL NO.
MP-322
DATE
9-17-65
NEED DATE
9-20-65
WORK ORDER
02-124-85-C-00

SUBJECT		
Analysis of Antenna Metal Samples		
REQUESTED BY	DEPT.	EXT.
S. A. Rocci	Antenna	
AUTHORIZED BY	REFERENCES	
D. A. Brownell <i>DA13</i>		
ASSIGNED TO	GROUP	PREPARED BY
M. Rogers	24-1	
INFORMATION DESIRED		
Determine by spectorgraphic or other analysis a qualitative chemical composition of ten metal samples labeled as follows:		
<ol style="list-style-type: none">1. Chips-shavings and miscellaneous foreign matter found in vicinity of bearing No. 1.2. Chips and shavings in runner splice bolt holes between bearing No. 1 & 2.3. Chips and shavings found in runner splice bolt holes between No. & 3 rear pad.4. Glob (chipped off pad) left hand inside bearing pad #1.5. Glob (chipped off pad) inside center bearing pad #1.6. Chips and shavings in runner splice bolt holes between bearing 2 & 3.7. Between bearing pad 1 & 2, foreign matter found in runner splice bolt hole - center hole only.8. Bearing pad or runner shavings slivers.9. Chips in oil		
XXXXXXXX		
10. Chips in oil		
The chemical composition of all samples was identical. They consist of iron, carbon, manganese, and silicon.		
<div style="text-align: right;"><i>Robert K. Rogers</i> _____ SIGNATURE <i>Senior Chem</i> _____ TITLE 20 Sep 65 DATE</div>		